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ELECTRICITY:

ITS THEORY, SOURCES, AND APPLICATIONS.

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ELECTRICITY:

ITS THEORY, SOURCES, AND APPLICATIONS.

BY

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EXAMINER IN ELECTRO-METALLURGY TO THE CITY AND GUILDS OF
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PREFACE.

THE fact that two editions, each of 2000 copies of this work have been readily purchased, together with letters received from electricians and students all over the world, may justify the author in believing that, in departing from the nearly universal system of electrical text-books, he has met a widely felt want.

There are two electricities known to the scientific world: the electricity which exists in nature; and the electricity which, created by mathematicians, exists chiefly upon the blackboards of the professor's class-room. It is the first of these electricities which this work endeavours to elucidate. The artificial electricity is very useful in calculating the effects of electricity: but that it does not satisfy earnest thinkers is manifest from the fact that recent text-books adopt and teach doctrines which were accounted utter heresies when this book first appeared.

A few words as to the object of the author may prevent some misconception. The work is not intended to enable the reader to "cram" for an examination, but to lead him to *think for himself;* not so much to give specific instructions as to any special case, as to assist in forming a clear conception of those general principles which include all cases. Space would not permit the full treatment of many subjects, and the science has now outstripped the powers of any one man, and ought to be specialized. The author has, therefore, dealt fully with his own more familiar branches, and left the details of those with which he has less acquaintance to be studied in works specially devoted to them. The principles of all are, however, explained, and it is hoped that these may include suggestions not to be found in the more specialized books.

This *edition is no mere reprint*, every sentence has been examined, and every source of information studied to bring the work fully up to date. One-third of the book is re-written; nothing of consequence has been omitted, but to make room for the new matter some of the less important illustrations have been set aside, and all unnecessary words cut down; but the work as a whole remains what it was, the expression of original thought and work, not a mere orthodox text-book.

As stated in the first preface, "the object has been to review the leading and essential facts, and to so systematize them as to form of them a *catalogue raisonné*, in which all information obtained elsewhere may be readily inserted, and be as readily available when required. Many mere facts found in all other books on electricity may here be omitted, or only slightly glanced at; but on the other hand, *principles* are dwelt upon, and the instruments necessary for their study fully explained, so that those who may have some mechanical aptitude may construct them for themselves, the very best possible way of understanding them."

It may be as well to remark that the history of electric discovery and progress does not enter within the scope of this work, but that, where occasion calls for reference to such subjects, it has been the desire of the author to give honour where honour is due, upon purely scientific considerations.

It should also be mentioned that this work originated in a series of articles in the *English Mechanic* and later papers in the *Electrician*; the new illustrations in the Chapter on Current appeared in the *Electrician*, and the curves of safe current in the *Electrical Engineer*.

117, GREEN LANE, BIRMINGHAM.
June, 1892.

CONTENTS.

CHAPTER I.

INTRODUCTORY.

Matter. Atoms. Ether. Valency and atomicity. Molecular types. Chemical notations, equivalent and atomic. Force and Energy as related to matter. Electricity not convertible into work. The two constitutents of electricity, a molecular function and energy .. .. Pages 1–15

CHAPTER II.

STATIC OR FRICTIONAL ELECTRICITY.

Primary condition of development. Electrics and conductors. The Electrophorus. Electroscopes. Primary experiments. Clerk Maxwell and Dr. Lodge on Charge, Potential, and Repulsion. Repulsion non-existent. The Fluid theories. Molecular polarization. How it produces electricity. Meaning of connection to earth. Earth not a reservoir. Surrounding surfaces and induction.—34. Frictional machines. Induction machines. The Wimshurst machine. Electrometers. Dry piles.—46. The Leyden jar. Condensers. Charges and induction. Quantity. Density. Attraction and repulsion. Tension. Potential, definitions of.—55. Distribution. Actions of points. Surface density. Induced charges. Condensation. Bound electricity, meaning of. Inclosed spheres. Inductive and conductive circuits. Capacity.—66. Relations of Static and Dynamic electricity. Dielectrics, properties of. Retardation. Specific inductive capacity, table of. Paraffin, uses of.—73. Discharge. Properties of the electric spark. Velocity of electricity; its dual nature. Polar actions and formation of the electric field of force. .. 16–80

CHAPTER III.

MAGNETISM.

Magnet and filings. Curve of force. Magnetic curves. Molecular constitution of magnets. Relation to electricity. Ampère's theory. Molecular theory. Hughes's theory. The magnetic field. Reason of attraction and repulsion. Bjerknes and Stroh: their mechanical illustrations. Magnetic force, laws of.—92. Magnetizing. Steel for magnets, forms of. Influence of heat. Terrestrial magnetism. The earth a magnet. Position of its poles. Variation. Horizontal intensity. Magnetic field, strength, moment. Magnetic intensity and capacity.—98. Auroras. Magnetic storms. Diamagnetism. Relation of magnetism to absorbed energy. Magnets *have no proper power* 81–100

CHAPTER IV.

GALVANIC BATTERIES.

Zinc in acid. Zinc and copper. Heat or energy developed. Molecular polarization set up. Definition of poles and plates. General principles. Sources of quantity and electromotive force. Amalgamation. Zinc. Sulphuric acid. Size of cells. E M F and size. Resistance. Current, constancy. Density of current.—115. Copper and zinc cells. Platinized silver. Various forms of construction. Porous jars. Electric endosmose. —120. Daniell's cell; various forms of: E M F of. Nitric acid, table of strengths. Aqua regia. Bichromate of potash. Chromic acid. Iron in batteries. Platinum.—137. Carbon: artificial: connection to. Circulation of liquids. Various constructions. Bichromate battery. Manganese. Leclanché. Alkaline cells. Fitting up batteries. Commutators.—151. Work and constancy of cells. Cost of working. Proper use of different batteries.—155. Secondary batteries, charge and discharge of. Planté. Faure. Formation. Construction. Loss of gases. Faure's battery. Other makes. Management, and work capacity of 101–170

CHAPTER V.

MEASUREMENT.

Galvanometers: needles for. Astatic needles. Laws of angles. Horizontal magnetic intensity. Tangent galvanometer. Sine. Curves of graduation. Sprague's Universal. Differential. Thomson's Reflector. Control magnets. Solenoid Types. Ballistic.—194. Voltameters. Ratio of gases to current. Calorimeters. Heating of wires. Coulomb-meters. Electric meters.—204. Principles of measurement. Natural units. The B.A. system. Absolute units. Force and Energy. Gravitation. The C.G.S. system Electric units, dimensions of. The practical units. Volt. Ohm, &c., general table of.—219. Resistance measures, construction of. Wheatstone Bridge. Potential, distribution of. Resistances and bridge combined 171–237

CHAPTER VI.

CURRENT.

What it means. The new ether hypotheses. The relation of current to matter and space. Conduction. Ohm's laws. Nature of E M F and resistance.—250. Slope of Potential. Curve of variable periods.—257. Hydraulic analogy. Alleged lateral transfer of energy. Induced currents. Hertz's experiments 238–262

CHAPTER VII.

CONDUCTIVITY AND RESISTANCE.

Specific conductivity. Alloys. Heat and conductivity. Resistance, definition of. Resistance as a velocity.—267. Impedance. Work as resistance. Counter or - E M F. Inductive resistance. Energy absorbed in magnetizing. Derived circuits. Shunts. Internal resistance of cells, measurement of.—272. Conductivity of Metals, &c.: Table of. Temperature correction. Dimensions of wires. Wire guage. Formulæ and constants of wires. Purity of copper.—284. Table of wires. Resistance of liquids. Earth circuit. Heating of wires. Dissipation of heat by conduction convection and radiation. Safe current in wires. Cost of conduction 263–297

CHAPTER VIII.

ELECTROMOTIVE FORCE.

Measurement of E M F. Voltmeters. Apparatus for experiments. Relations of energy and matter. Mechanical equivalent of heat. Intrinsic energy. Combustion. Salts.—308. Table of properties of the elements. Energy of chemical processes. How energy becomes E M F. The equivolt.—314. Table of correlation of units, &c. Contact and chemical theories. General law of energy. Electric circuit, phenomena of. Positive metal sets up E M F. Action at negative plate.—323. Table of E M F of batteries. Details of energy in electric actions. E M F and chemical affinity. Work and the square of current Energy expended in circuit. Potential considered as energy 298–340

CHAPTER IX.

ELECTROLYSIS.

Terms used. Atomic charges. Di-electrics and electrolytes The Dissociation Theory. Velocity of ions. Action of the solvent.—348. What is an Electrolyte? Conduction process. Molecular structure. Elements. Valency. Berzelius' theory and Faraday's opposed and united. Gas volume.—353. Electric equivalent. Generating and decomposing cells. Diagram of full circuit.—357. The laws of electrolysis. General law of minimum energy. Formula of work. Counter E M F. Transmission in liquids. Secondary actions.—362. Action at electrodes. Mixed electrolytes.—366. Water not an electrolyte. Typical reactions. No transfer of ions. *Experimental apparatus.* The work of electrolysis. .. 341–373

CHAPTER X.

ELECTRO-METALLURGY.

Electrotyping and Electro-plating. Preparation of objects. Cleanliness. Cleaning processes for different metals. Old work.—380. Moulds. Plaster of Paris. Elastic moulds. Insects and flowers. Conducting surfaces. Stopping off.—387. Smee's laws. Strength of solutions. E M F and resistance required. Density of current. Tension.—393. Rate of deposit. Effects of position. Circulation. Size and distance. Apparatus. Principles of solutions.—400. Depositing copper. Bronzing. Rate of work. Cyanide of potassium.—407. Silver depositing. Spoilt solutions. Gilding. Coloured gold.—417. Nickeling. Iron. Aluminium. Platinum. —424. Refining lead and copper. Alloys. Brass and bronze deposits 374–430

CHAPTER XI.

TERRESTRIAL ELECTRICITY.

Earth currents; causes and laws. Magnetic storms. Supposed static charge of the earth. Cosmical electricity.—434. Electricity and gravitation. No magnetism in space. Clerk Maxwell's theory of light. Hertz's undulations, their nature. Atmospheric electricity.—439. Evaporation stores energy. Potential energy of vapour. Earthquakes, volcanoes, and cyclones. Thunder-storms. Ball lightning. Duration and brightness of lightning. Dr. Lodge's experiments. Oscillations.—447. Lightning conductors: laws of. Earth connections.—451. Faraday's comparison of Static and Dynamic electricity explained. Quantity and Potential both included in the usual expressions 431–453

CHAPTER XII.

ELECTRO-MAGNETISM.

Electric actions in conductors. Reactions of currents on magnets. Static and magnetic charges are potential energy stored. Right and left handed helices.—462. Magnetic definitions and symbols. Saturation of iron. Hysteresis. Electro-magnets. Laws of traction and attraction.—469. Construction. Induced currents in conductor crossing the field.—475. Dynamo-electric machines. History of the earlier forms. Evolution and development. Principles of all dynamo machines. All matter exists under a balance of varying forces. How magnets develop currents.—491. The Gramme machine, the Siemens machine, and others.—501. Field magnets. Shunt, series, and compound machines. Laws of E M F developed. Efficiency of machines.—505. Electric motors: various types. Relative efficiency of motors.—509. Cost of working. Energy of fuel. Gas as fuel. Cost of mechanical energy. Cost of electric energy.—512. Transmission of energy. Rotary field dynamos.—515. Induction coils, laws and construction of. Mercury breaks. Dimensions of noted coils. Medical coils. Management of wires.—531. Transformers. Oil insulation. *Motor generators* 454–534

CHAPTER XIII.

ELECTRIC LIGHTING.

Light a motion and a perception. Sound; absorbed notes. The spectrum: dark lines. Light, ether and matter. Tesla's experiments. Draper's experiment. Hertz and Clerk Maxwell.—543. Degrees of Temperature, Table of. Ratios of light to energy. Photometry: standard of light: chemical measures. Absorption. Distribution of light.—548. Light not produced from electricity; energy its source in all lights alike. The voltaic arc: its temperature. Colours by arc light. Penetrating power: resistance and E M F. Products of the arc. Uses of the arc light.—553. Arc lamps: differential principle. Jablohkoff and other "candles." Preparation of carbons.—556. Incandescent lighting. Atomic heat and volume: radiation capacity. Swan's first lamps.—562. Form and size of carbon wires. Efficiency of lamps. Advantages of incandescent system. Law of light ratio to current and work. Cost of the light 535–569

CHAPTER XIV.

MISCELLANEOUS.

Telegraphy. Duplex and quadruplex. Automatic transmission. Electric musical instruments. The motograph.—573. Electric bells: construction and system. Switches. Phonautograph. String telephone. Phonograph. —579. The telephone: order of invention. Current required. Construction. Action of the telephone. Telephone circuits.—587. Transmitters. The microphone. Theories of the microphone. Induction. The law of speaking distance. London and Paris line. Telephone system.—596. Radiophony. Selenium and its properties. Photophony. Telephotography. Hughes' induction balance and sonometer. Edison's micro-tasimeter.—607. Thermo-electricity. Piles. Conservation of electricity.—611. Electric welding. The Hertz experiments; radiations and undulations. Electro-magnetic repulsion. Elihu Thomson's experiments. Electricity a function of matter 570–619

CHAPTER XV.

DICTIONARY OF TERMS.

Short definitions and explanations 620–634

INDEX 635–647

36

ELECTRICITY.

CHAPTER I.

INTRODUCTORY.

1. Superficial thinkers commonly deride what they call "superficial knowledge," and quote the poet's erroneous dogma that "a little knowledge is a dangerous thing." A little knowledge may be most valuable, and in science it is certain, that, to understand any one subject thoroughly, we must know something of many other subjects; such knowledge can only be slight or superficial, but we never know at what moment some apparently small piece of knowledge may throw a flood of light in an unexpected direction; so that the student of any science should endeavour to get a wide knowledge, even where he cannot secure depth, but he should take care that his knowledge is accurate, so far as it goes, and should carefully recognise its true limits. A little knowledge only becomes dangerous when it is believed to be greater than it is.

2. Lord Derby, in one of his addresses to students, defined knowledge as that which a man had so secured that he could produce it at any moment out of his own head; that definition may be correct from the point of view of a crammer for examinations; it is not true as relates to the practical man of science, for perhaps the most valuable part of his knowledge is the knowing where to find what he wants when he wants it. The knowledge we can carry in our heads may be compared to the money in our pockets, the other is our bank account. The man who tries to fix all his knowledge in his own memory rarely gets much, and is very apt to injure his health, and dwarf his reasoning powers. The great importance of *theory* is that it links together the whole range of a science, enabling us to remember without taxing the memory; it often gives us safe knowledge of facts which we have never known as such, while it systematises all the classes of our knowledge, as a well-arrange system of shelves does for the books of a library, or the goods in a warehouse.

3. In the study of electricity and its various applications, we require to have some knowledge of the fundamental principles of mechanics, the laws of motion, energy, force, and heat, and above all we need some considerable acquaintance with the general principles of chemistry, especially if we mean to study it as one of the prime agencies of nature, instead of as a mere department of mathematics, as is done in many text-books.

In this work the former is the point of view adopted, and therefore in some cases it appears best to treat directly some branches of science not often referred to in electrical books. This is especially the case with chemistry, and as this science has gone through great changes of late years, and its terms and doctrines are differently treated by different writers, I think it better not to refer the reader to works treating of this branch of knowledge, but to give here the general outline of the facts, principles, and terms which will be employed, to serve, as it were, as an outline chart by which we may afterwards travel intelligently through the land we desire to explore.

4. MATTER.—Of the essence or nature of matter itself we know absolutely nothing, and never shall know anything; but of its properties, whether they be inherent in its own essence, or due to the action of forces connected with it, we know a good deal.

Matter, as known to us, consists of certain forms which we call elements, because they are the simplest substances we have yet attained to. These may, for all we know, be composed of varying mixtures of yet simpler forms of matter; but true science, as distinguished from metaphysics, refuses to admit the "*may be*," but rests on what is *proved*. Therefore, in science, matter means the elements and their compounds.

5. ELEMENTS.—Of these at present sixty-five are known, besides several recently discovered or supposed to have been isolated. They exist as gases, such as hydrogen and oxygen; as liquids, like bromine and mercury; and as solids, such as carbon and the long list of metals; but these physical states are not essential to their nature, they depend only on their existing relations to force, as heat and pressure; and as we can, by altering the conditions of force, cause most of them to pass from one state to the others, so there is no reason to doubt that every gas can assume the solid form, and every solid become a gas, under sufficiently altered conditions of force.

6. ATOMS.—There is abundant evidence that these elements exist in the form of ultimate particles called atoms, possessing definite dimensions and weight. Though these atoms are practically infinitely small, and beyond our powers of measurement, or even conception, yet their existence is not a mere hypothesis,

but a logical deduction from well-proved facts. All the actions of matter prove their existence, and the whole framework of modern chemistry, and, indeed, of all the natural sciences, is based on the atom.

There have been many discussions as to the actual existence of atoms, which have been really battles about words. "Atom" means *indivisible*, and it is obvious that any particle having dimensions and weight, however small, must be theoretically capable of being divided: but we need not encumber ourselves with any hypothesis as to the atom being infinitely hard and so on, as subtle reasoners about things beyond our knowledge continually do; we may simply consider the atom as the ultimate particle of each form of matter, and that, if divided, it would no longer remain that form of matter.

The atom has several relations to force: (1) to gravity, which depends on its mass simply, without reference to its nature; (2) to heat, which for each physical form of matter is the same for all atoms; (3) chemical affinity, which varies between every different class of atoms.

7. ETHER.—Besides ordinary matter, known to us, specially as the elements, and generally as possessing *inertia*, and the attracting force of *gravitation*, and as the agent by which *energy* is manifested, there must be something filling all space, by which energy, as light, &c., is transmitted. What it really is, we have no means of ascertaining, nor are we ever likely to learn except by deduction from its actions, because it is impossible to lay hold of and analyse it; but the interesting researches of Dr. Crookes into those extreme vacua now obtainable by means of the mercury pump (and which are readily carried to the one millionth of an atmosphere) strongly suggest to the scientific imagination that this so-called "fourth state of matter" may actually be the interstellar ether, or be a stage towards it. If so, the elements must have undergone so complete a transformation, either into a non-atomic condition, or into a more primal state, that the *ether* no longer answers to the fundamental definitions of *matter*. It has no inertia, because it produces no friction or resistance to motion, and therefore does not absorb any energy in transmission. It has no gravitation force, for if it had it would vary in density at varying distances from the bodies in space, and would therefore not transmit light undisturbed.

But whatever may be the actual nature of the thing which fills space, all systems of physical philosophy alike require this so-called "ether"; for so far as the probabilities of several hypotheses are concerned, there is no difference between this one ethereal substance transmitting the impulses of the forces, and a luminiferous agent issuing from the sun, or an electrical fluid pervading space and matter, except that the first—the modern theory—is by far the most simple and most accordant with the facts needing explanation.

8. This hypothetical ether is being gradually made to fulfil more and more of the functions for which the older philosophers invented separate "fluids," and in this there lies a new danger for real science. Although we know absolutely nothing about the ether, and these applications of it are mere guesses, yet when a word is invented to cover a difficulty, people easily come to believe that this word actually explains the matter, and the hypothesis gradually assumes the rank of a theory and at last an accepted dogma. For instance, Sir W. Thomson said that the mode in which the ether transmits the undulations of light, might be compared to the vibrations set up in a mass of jelly: this is a useful illustration, but it is nothing more than a parable or fable, conveying a truth through unreal figures. Yet it is becoming common for lecturers and professors to speak of the ether as a jelly-like substance, while the mathematicians already commonly commit the absurdity of applying formulæ and arguments based upon the properties of *matter*, to this entity, of which our most certain knowledge is, *that it does not possess those properties.*

Unfortunately, mathematical theorists too readily adopt the practices of the old metaphysicians: they are apt to meet a difficulty with the phrase, "If we assume," and to build fearlessly on these assumptions, which generally take the form of giving to the ether some arbitrary property which will fit it to the case. Now hypothesis is useful in science, but it must be derived from the facts, not invented merely to provide an imaginary explanation. A book-keeper could always furnish a satisfactory balance-sheet, if the auditors allowed him to set up imaginary credits and draw upon them at pleasure. But there would be trouble in realising the assets, and it is the same with these fictitious explanations. A wise humility will recognise its ignorance, and a wise patience await fuller knowledge, rather than invent an artificial knowledge which can only serve to disguise people's real ignorance from themselves, and to make them contented with it.

9. ATOMICITY OR VALENCY OF ATOMS.—Chemistry has now undergone a complete revolution, and one of the leading features of the new system is the idea of molecular types, due to the atoms having different exchangeable values. There was *an old opinion that* matter had no real existence, and that atoms

were simply centres of force. The modern idea is, that though the atom is a material body, it acts as a centre of force, and that the atoms of different elements differ by possessing one, two, or more such centres, or foci of influence. Hence the elements are classified as monads, monatomic or univalent, having only one attraction, such as hydrogen, chlorine, &c.; dyads, diatomic or bivalent, having two attractions, as sulphur, or oxygen; triads, triatomic or tervalent, with three attractions, as nitrogen; tetrads, tetratomic or quadrivalent, having four attractions, as carbon, and so on; this division being mainly based upon the relative volumes occupied, in the gaseous state, by the weights accepted as constituting the atom of each element.

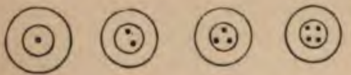
The words atomicity and valency are frequently used as synonymous, but there is a tendency to attach the first term more to the theoretical explanation of the nature of the atom, while valency expresses the fact that atoms of the weights now accepted, do in combination or substitution replace 1, 2, 3, or 4 atoms of hydrogen. This involves no theory, and whenever I use the word valency it must be understood as expressing this fact, rather than the explanation which follows.

10. It is conceived that the atoms of which matter is built up are not in absolute contact, but are separated by spaces (containing ether) in which they move freely under the several forces to which they are exposed, these motions replacing in modern theory the atmospheres of forces or fluids which used to be believed in. The atoms are held together by the attraction or force which we call affinity, exerted across these intervening spaces, through the agency of the ether.

In any act of combination or decomposition, nothing less than one atom of any substance concerned can take part or undergo a change of its relation to other substances, but these relations are governed by the number of attractions proper to itself. Thus an atom of hydrogen (1) can only combine with one atom of chlorine (1) to constitute hydrochloric acid; two atoms of hydrogen (1) unite with one of oxygen (2) to form water; three atoms of hydrogen with one of nitrogen (3) form ammonia; and four with one of carbon (4) make marsh gas, these being four of the typical forms to which chemical combinations are referred, not merely for convenience, but because they are all bodies actually existing, and playing important parts in the chemistry of nature, and also because they are forms which would result from the several atomicities, if these really exist. In all cases, however many atoms unite to form the new body, they condense into the one unit or molecular volume.

As to the actual shapes of the atoms we know nothing, but to enable readers more clearly to realise the theory set before them, I employ diagrams in which the several atoms are represented by circles containing dots to mark their atomicities, and surrounded by another circle to mark the space which separates them from each other, and in which they move; but it must be understood that these diagrams are only aids to the imagination; they represent ideas, but by no means must be taken for actual pictures of the things they may aid us to conceive. We may therefore picture the various classes of atoms as in Fig. 1.

Fig. 1.



11. The Molecule.—Formerly the words atom and molecule were treated as almost synonymous, but the rapid growth of modern chemistry has required a more exact definition of ideas, though even yet, as to compounds, the word molecule is not unfrequently used where atom or radical would be more correct. The strict meaning of the word now is the smallest quantity of a substance which is capable of separate existence as a free body. With this meaning the word is equally fitted for use in chemistry and in general physics.

It is therefore a body in which all the attractions or valencies are satisfied, leaving the combined atoms to act as a whole from one centre, so far as such forces as gravitation, cohesion, heat, &c., are concerned. A body whose atomic attractions are not thus satisfied, though it be complete in one chemical sense, and has a real existence, yet cannot exist by itself; it therefore is not a molecule, but a compound atom or radical, because indivisible without change of nature; to become a molecule it must unite with another body or bodies sufficient to satisfy its attractions.

This applies equally to elementary and compound bodies, and therefore every molecule must consist of at least two atoms—distinct, yet united—and acting as a whole on surrounding bodies. Hence a piece of copper wire is not built up of atoms, as in Fig. 2, but the atoms are coupled together first, as molecules, as in Fig. 3.

It is evident that as regards simple elements, two atoms, whatever their atomicity, can form a molecule by satisfying each other, and this is the usual form of elementary molecule; but there are some of which the molecule may probably contain several atoms, and others, such as carbon and phosphorus, which exist in several conditions, or allotropic states, the cause of which may be, that the molecules in these different states contain different numbers of atoms and different energies.

This last word marks the distinction between the chemistry of the past and that of the growing future. Until lately, chemists only took account of the material atoms and their arrangement. Now they begin to recognise that the atoms and molecules have another constituent besides matter; that energy, stored probably as internal motion, is equally real and important. Hence thermo-chemistry is becoming an important and essential subject of study.

FIG. 2.

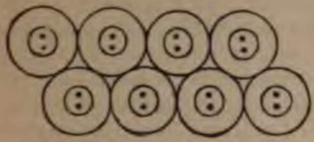
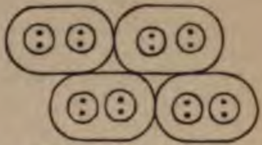
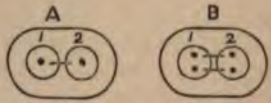


FIG. 3.



12. MOLECULAR TYPES.—When different elements enter into combination, the number of atoms forming the molecule will depend on the relative valencies of the several atoms, and hence we arrive at certain typical forms or molecular skeletons, to which all compound bodies are related. A univalent atom can only join a single univalent atom, and this furnishes the first type, Fig. 4. Here the two atoms, 1 and 2, in molecule A, may be both hydrogen H' H'; or both chlorine, Cl' Cl', forming the free molecule of hydrogen or chlorine; if 1 is hydrogen and 2 chlorine we have H' Cl', the molecule of free hydrochloric acid; and if we substitute sodium for the hydrogen in this, we have Na' Cl' the molecule of common salt, and if we now substitute iodine for the chlorine we have Na' I' iodide of sodium. Fig. 4 A, in fact, shows a molecular frame, which we may fill up at pleasure with univalent substances without destroying the molecular constitution.

FIG. 4.



The molecular equilibrium will not even be destroyed if we substitute a compound atom or radical for either or both of these atoms; thus, returning to the sodium iodide, the iodine may be replaced by cyanogen Cy' (which being $C^{iv} N'''$ has one attraction unsatisfied) producing sodium cyanide Na' Cy', and then finally the sodium may be exchanged for the monatomic radical of alcohol, ethyl C_2H_5 to form cyanide of ethyl. I have gone somewhat fully into this type, in order to give the general principle applicable to all—viz. that any typical atom in any molecule may be replaced by another atom of similar valency, without altering the arrangement of the molecule, and in so doing its chemical properties will only be gradually affected, according to the properties of the substituted atoms, without changing its relations to electrical force.

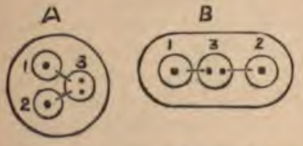
Molecule B, in Fig. 4, is intended to show that the same type includes bodies of higher valency, where only two atoms of equal valency, each satisfying the other, are contained in the molecule; so that this type includes the molecules of the elements, and of many radicals in the free form, though A, Fig. 4, is that which is called the hydrochloric acid type.

The next is the WATER TYPE $\left.\begin{matrix}H\\H\end{matrix}\right\}O$ or H_2O, in which one bivalent atom unites with two univalent atoms, Fig. 5.

Here, as in the first and in all other molecular forms, each atom is capable of being exchanged for any other of equal value: thus, the hydrogen atom 1 may be replaced by potassium, and we have $\left.\begin{matrix}K'\\H'\end{matrix}\right\}O''$ hydrate of potash; again, 2 may be similarly replaced, giving $\left.\begin{matrix}K'\\K'\end{matrix}\right\}O''$ or K_2O, potassium oxide; or instead of the hydrogen, the oxygen atom 3 may be exchanged for another bivalent atom, as sulphur giving $\left.\begin{matrix}H'\\H'\end{matrix}\right\}S''$ or H_2S, sulphuretted hydrogen.

Two ideal forms of this molecule are given, because neither will convey the whole truth; for we may conceive that both the hydrogen atoms are equally held to the oxygen in water, which is the form A, or one of them may be held more strongly than the other. There is good reason to suppose that the latter is the case in ordinary circumstances, and that atom 1 of the H is more closely united than 2 to the O; that HO first form a univalent radical known as hydroxyl, to which the second atom of hydrogen is united. A strong support to this idea is found in what are called isomeric bodies, containing exactly the same elements in the same proportions, yet having somewhat different properties. It is evident that in Fig. 5 B there would be a difference according as atom 1 or 2 was replaced by another element. Still, Fig. 5 A is also true, for both 1 and 2 may be removed together and replaced by a single bivalent atom, in which case, however, we should consider the type was changed *to that of Fig. 4 B.*

FIG. 5.



This capacity for change of type is important to understand, because it explains the different formulæ given for the same substance. Under different treatment, either by heat, electricity, or chemical action, the same substance will break up in different manners, just as a crystal may be broken along different lines of cleavage. Under the influence of an electric current there is good reason to suppose that the molecule, Fig. 5, takes the form A, the atoms 1 and 2 passing to one pole, and atom 3 to the other pole, while under the action of potassium it acts as B, parting with only one atom of H.

13. It is not necessary to go further into the subject of the types of molecular construction until the action of the electric current in electrolysis has to be considered; at present the main thing is to obtain a clear conception of molecules as the ultimate particles of matter in all its ordinary forms; as the bricks, so to speak, with which the substances known to us are constructed on regular systems of architecture, and to comprehend that they have a capacity of separating into at least two parts, which are held together by a mutual attraction.

It will be seen that there are thus two classes of molecules—

(1) *Molecules, which are also atoms*, being indivisible without change, as water, and all salts and acids. These molecules are held together by high affinities, varying in each case, and require considerable force for their decomposition.

(2) *Molecules formed of two similar atoms* or radicals, held together by their unsatisfied attractive foci, but by a feeble affinity; these are capable of division into two similar parts, and that by a small expenditure of force. This is the state in which exist, as free bodies, the elements and those compound radicals (such as cyanogen) which have many of the properties of elements, though known to be compounds.

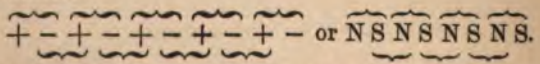
14. We may conceive the molecule as representing, on the infinitely small scale, the solar system itself, which is built up of several systems or parts, each complete in itself, yet all linked to each other and forming a balanced whole: thus Mercury and Venus stand as single atoms, the earth, Jupiter, and Saturn, with their moons, resemble the compound atoms or radicals composed of several distinct atoms so united as to play the part of a single atom in the mighty molecule, which again forms but an infinitesimal part of the complete universe, held within it by forces acting across infinite space, as our molecules are united into visible substances by the forces of cohesion, &c.

15. Before leaving the subject of the construction of compound bodies, one *general principle* must be indicated, not

only because of its great general importance, but because it is the foundation of the whole theory worked out in this book.

The atoms of each element, having each their definite charge of energy, probably in the form of motion, when united as a molecule must be conceived as giving up a part of their individual energy or motion, to constitute that belonging to the partnership. In this new arrangement there appears to be a difference set up between what in the case of elements were two similar atoms. This difference is theoretically explained in various modes: it is supposed that one possesses a charge of the imaginary positive electric fluid, and the other of the negative, and the mutual attraction of these charges holds the molecule together; others suppose that one atom gets a special charge of the hypothetical ether.

Be the cause what it may, we have the fact that there is something in the molecule which enables it to manifest different actions from its two constituents, whether these are similar atoms or different elements; molecules under certain conditions do manifest attractions corresponding to the N and S poles of magnets, or to + and − charges of electricity, and as a consequence they possess the faculty of arranging themselves in a serial or polar order, which is therefore called *polarisation*, and which constitutes a material chain, through which energy is capable of transmission. In this state the atomic energies react partially upon their neighbours in the polar chain, and under the influence of an applied force the molecules can break up, and the adjoining atoms, exchanging partners, unite to form new molecules; the diagrams show these actions, the upper brackets representing the original order, and the lower ones the new formation:—



This illustrates the action in electrolysis or electro-chemistry, where at each end of the chain one element of the molecule is set free.

16. NOTATION.—The various chemical facts and reactions are concisely expressed in symbols, which generally are the first letter of the name of the element in English or Latin: each such symbol stands for 1 *atom* of the element, multiplied when necessary by a smaller figure following it a little below the line: all reactions are expressed by first writing in symbols the construction of the substances set to act upon each other, divided by + from the substances produced, and the two should exactly represent the total atoms engaged. There are many

modes of expressing the same bodies in different formulæ according to the special theory of constitution adopted, or the particular view of the matter intended to be described: and there are two distinct systems in use.

(1) *The Equivalent.*—This system, used in all the old books, is based really on oxygen (which was called 100), and the weight of hydrogen which combined with oxygen being called 1, the equivalents of other substances were afterwards reckoned from this. Hence water is in this system called HO (1 + 8 = 9).

(2) *The Atomic.*—This, which is called the "New Notation," is generally adopted in the modern chemical books. It is based on the fact that water contains two *measures* of hydrogen to one of oxygen, and this being conceived to show the atomic relations, water becomes H_2O; H being still called 1 as to weight, it becomes necessary to call $O = 16$, and in consequence most of the metals have their weights similarly doubled as compared with the equivalent notation, while the number of atoms of those which are unchanged (the univalent elements) have to be doubled. The following example of the action of sulphuric acid upon nitrate of soda exhibits the two systems:—

Equivalent.

$$\overset{\text{Salt.}}{\underset{23\quad 62}{\mathrm{Na\ NO_6}}} + \overset{\text{Acid.}}{\underset{1\quad 48}{\mathrm{H\ SO_4}}} = \overset{\text{Salt.}}{\underset{23\quad 48}{\mathrm{Na\ SO_4}}} + \overset{\text{Acid.}}{\underset{1\quad 62}{\mathrm{H\ NO_6}}} = 134$$

Atomic.

$$2\underset{23\quad 62}{\overline{\mathrm{Na\ NO_3}}} + \underset{2\quad 96}{\mathrm{H_2\ SO_4}} = \underset{46\quad 96}{\mathrm{Na_2\ SO_4}} + 2\underset{1\quad 62}{\overline{\mathrm{H\ NO_3}}} = 268$$

This means that the nitrate of soda on being mixed with sulphuric acid decomposes into sulphate of soda and nitric acid.

The equivalent system is really the best for electrical purposes, and is retained by many of the best French chemists; but as the atomic notation is now universally adopted by English chemists and writers, it is necessary to use it, to avoid confusion and misunderstanding by readers.

17. FORCE.—Until recently the words force and energy were used indifferently in the sense of power; but they are now differentiated, and *force* expresses causes, while *energy* expresses work, and capacity for work. But there are two uses of the word "force": gravitation and all forms of attraction may be regarded as forces of nature, and heat, electricity, &c., are called

forces; but according to the modern ideas "force" covers any agency which can generate a motion, or arrest or change its direction; and is defined as the generator of "momentum" which includes mass as well as velocity, and this definition enables us to express the "energy" involved in any action in terms of unit force adequate to the production of that energy. We may regard force therefore as—

I. Related to mechanical energy, or motion of matter as such, which, like gravitation, is connected with the absolute weight of matter in motion.

II. Force related to the *atom* of matter. Heat does not act on matter by weight or by bulk, but atom by atom. The atom of iron weighs as much as 56 atoms of hydrogen, copper 63·5, silver 108, gold 197. If these relative weights of the several substances (being solids) are heated to the same temperature, and each transferred to an apparatus capable of measuring the heat absorbed, it will be found that, different as are the quantities of matter, all have absorbed the same quantity of heat. Of course the experiment is so delicate that perfectly exact results cannot be obtained, and certain corrections have to be made; but the deduction is certain, that heat acts upon matter in its several physical states, not according to its weight, but according to the number of atoms it contains.

The relation of compound substances to heat is not so simple as that of elements, though still a distinct law is traceable throughout; each molecular form has its own relation to heat, which is due to the number of atoms it contains, and their state of combination.

III. Force related to the *molecule* of matter: such are the forces of electricity and magnetism which depend on the motions and polarity of the molecules. Heat also is related to the molecule in connection with internal work, such as expansion and the latent heat of fluidity; that is to say, there is a motion of the molecule as a whole, as well as a motion of the atoms within the molecule. Hence we learn that in the gaseous state, under the same conditions of force, all molecules, whether simple or complex, occupy the same space, so that heat and pressure produce the same amount of expansion or contraction upon all, proving that the force is acting upon the molecule as a whole, not upon its component atoms. Recent discoveries appear, however, to limit this to a moderate range of temperatures, and indicate that the law of Dulong and Petit is not a general but only a partial truth.

IV. Force related to the ether. This includes light, and other forces issuing from the sun.

This classification is suggestive, as throwing light on many obscure subjects, especially when combined with the now recognised fact that all the forces are capable of transformation into each other; it enables us to conceive that if the undulations of the ether produce the effect which we call light, those same undulations, when transferred to the material atoms floating, as it were, in the ether, produce the effect we call heat; and thus we may apprehend the reason why heat and light are so constantly coexistent and seemingly identical in nature; it also explains how it is that while the sun transmits us such a constant supply of heat as well as light, yet to all appearance the space between the sun and us is devoid of heat; the sun transmitting *pure energy* through the ether, which assumes the form of force suitable to the objects which absorb it, or the organs constructed to perceive it.

18. ENERGY.—The idea conveyed by this term is replacing many of the old fluids, and functions of the ether: it is difficult to define, because such a name conveys the idea of some actual existence, as do the words light, heat, electricity, &c. But these are now seen to be not things, but actions, and energy is therefore a word which expresses the general agency of which these are but forms. Energy is really motion, or the capacity to pass into motion. Actual motion, whether mechanical or as temperature or sensible heat, &c., is called *kinetic*. The capacity to pass into motion, as where energy is stored in a strained spring, or in chemical decomposition or what used to be called "latent heat," is called *potential*. The doctrine of the "conservation of energy," which has played so important a part in modern science, teaches that "energy" is as indestructible and as impossible to be created as is "matter": that as in the various actions which occur matter is neither created nor destroyed, but only changes its combinations and forms, so energy (derived from the sun) is stored up in effecting the reduction of water and carbonic acid to form wood or coal; remains "potential," and reappears in combustion "kinetic" as heat, and passes by the aid of the steam engine into mechanical work; all of these being forms of energy having measurable relations to each other. This is in fact the counterpart of the doctrine of the co-relation of the forces. Energy thus is the result and the measure of the action of force. In this enlarged view of force and energy we find the underlying truth which justified an old and apparently abandoned theory, for in modern science, *energy* or internal motion is gradually assuming the position of phlogiston in the old chemistry.

19. *ELECTRICITY.—The various* theories of the nature of elec

tricity are explained in their proper places. Here it will suffice to say, that electricity is not a thing, but only a word, grouping together natural facts and ideas as to their cause, and that a great error is commonly committed, even by eminent scientific men, by confusing distinct things under this one name; we speak of torrents of electricity poured forth from the thunder cloud, and from the dynamo machine, we might as well class all the work done by hydraulic machinery, and the phenomena of the ocean, under the name of "water." Electricity comprises phenomena of two distinct orders, those of electric quantity, and of electric force; it is the first of these only to which the name electricity properly belongs, as compared to a thing, a fluid; as a matter of well-known fact electric quantity is very small in the lightning flash. The lightning is simply a case in which an enormous amount of energy is charged upon a small electric quantity. This "quantity" is related to the molecular constitution of matter, as is manifested in chemical actions. We may find a very perfect analogy in hydraulic works, where energy is transmitted and work done through the agency of water in pipes. Electric "quantity" may be compared to bulk of water transmitted, while electric "force" resembles the pressure put upon the water, as will be seen hereafter.

20. According to the theory adopted in these pages, electricity is not material or a quasi-material fluid; nor is it a special force, or energy: much argument has been used by partisans of each of these views, to prove the other erroneous, and both sides are quite successful in the effort. But unite the two, and we have a clear truth. It is energy charged in a special manner upon ordinary matter, and developing special relations among its molecules. Since the first edition of this work was published, this view has gained much ground, and many things which then were regarded as heresies, are now generally adopted as true scientific principles.

21. We not uncommonly hear of the "conversion of electricity into light, heat, or mechanical energy." This is an error, due to the confusion of the two factors of electricity. Electricity calls for two distinct expressions, Q, and Q^2. The first is that which the old theories considered to be material or analogous to matter, and represented to the mind by the expression "imponderable fluid," but which the new theory considers to be numerical, the action of definite material quantities or molecules. This, which is properly the "electricity," can no more be converted into heat or anything else, than can the water in a steam boiler or hydraulic engine. The second, Q^2 is the

electric energy, the true cause of electrical phenomena, and convertible into heat and work, because it answers exactly to the mechanical energy (also convertible) carried by the water as steam from a boiler, or under pressure in the hydraulic engine.

22. But while scientific men are fast coming to this view of electricity, and it is very commonly employed, more particularly in connection with dynamic electricity or galvanism, still the new theory is rarely fully set forth and substituted for the old fluid theories, and therefore it is very difficult for students to obtain that clear view of the subject which is desirable, especially as all the older terms of the science were devised in connection with the old theories, and are exceedingly ill-fitted to convey the new one without producing much confusion of ideas.

This work in its original form was intended to meet this requirement, and the plan adopted has been to commence with a few leading facts and principles, then describe the various forms of instruments necessary to examine the actions of the force, and by their aid trace out the general laws and fundamental principles of the science, after which the applications of the force, the nature of which has been thus examined, will become far more intelligible than by piling up isolated facts, or describing mere processes, however practically valuable.

To do this in a perfectly methodical manner is always more difficult in a natural science than in mathematical studies, because it is impossible to understand the most elementary facts without a considerable acquaintance with the subject; and, on the other hand, to lay a wide foundation in elementary facts before dealing with their theory would not fulfil the purpose of both leading the beginner in the best course, and showing the more advanced how to adopt the new interpretations and to free themselves from the mental confusion produced by the old theories, while at the same time furnishing the practical man with the interpretation of the processes he employs.

CHAPTER II.

STATIC OR FRICTIONAL ELECTRICITY.

23. It is now generally admitted that motion is convertible into heat, and the effect of friction is a familiar illustration of this. If we turn a grindstone, it requires a certain force to start it, and then the expenditure of a certain amount of energy to keep it in motion, to overcome the friction of its bearings and the air, and then so much more as is needed to overcome the resistance of any object we press against it. If we get the stone into rapid motion, and then cease to work at it, it will run a certain time before stopping; but if we hold against it a piece of steel, it will come to rest in less time, because its momentum is absorbed by the friction; at the same time the steel becomes hot, and if the stone is dry, we see a shower of sparks fly off, visibly exhibiting the transformation of the energy of motion into heat.

But if we cover the edge of our grindstone with certain substances, guttapercha for instance, and establish certain other conditions, we obtain a very different result; instead of heat we develop electricity. When we ask, whence does this electricity come? the doctrines I am setting forth teach that it is like heat, the result of the conversion of mechanical motion into molecular motion—that which of these forces we obtain depends upon the conditions to which we expose the molecules, and further, that as soon as we allow the electricity to act, it either generates heat, as we see by the spark, or else does some work which represents the heat.

24. This development of electricity by friction was observed in early days, and we derive the name itself from *electron*, the Greek name for amber; the substance by which the phenomenon of attraction after friction was first manifested. In later times it was found that many substances possess this property, and such were called "electrics," and those bodies which do not appear to possess it, "non-electrics." The distinction is more apparent than real; for under certain conditions, both classes develop electricity under friction, the true cause of the difference being the different power of substances

to conduct electricity, on which property is based another classification into conductors and non-conductors. But here again, increased knowledge has shown that no such broad definition can be sustained, the distinction being one of degree only, not of essential property. All substances are electrics, and all conductors, though some conduct very slightly. Faraday, finding that conduction was effected by "induction" of polarity from molecule to molecule, introduced the term *dielectric*, which is commonly used now in the sense of a body which transmits electric induction, or stands high in the list of electrics.

25. Another general distinction may be drawn among these substances, although the lines of demarcation cannot always be exactly defined.

Conductors are metals (also carbon in some form) or substances of which metals, including hydrogen as a metal, form one of the molecular subdivisions or *ions*.

Dielectrics are substances not containing metals (except hydrogen, which in them does not replace a metal or form a separate constituent) and whose molecular constitution is complex.

In the former class electricity is *dynamic*, and the *conductive* circuit is set up: in the latter the *static* phenomena are developed, and the circuit is *inductive*.

26. STATIC ELECTRICITY is however a misnomer: it has no existence: the phenomena are due to static strains, but there is always a gradual loss, called *leakage*, which is the current due to the conductivity of all circuits; and every motion set up by so-called "static" electricity implies a transfer of energy occurring in a field of force, set up in the form of strains in the particular "inductive circuit" in which the motions occur.

27. We may now pass to experiments, from which alone knowledge is to be obtained, and I shall indicate such simple forms of instruments as any one can obtain or make for themselves, but which will go far to demonstrate principles. The first things needed are a source of electricity, an indicator of its presence, and the means of collecting it and examining its actions.

If we take a stick of sealing-wax, or a rod of glass, in one hand, and rub it with a piece of dry cloth or fur, we have the fundamental experiment from which electrical science grew, for we find that we have developed a force upon, or induced a condition in, the rod which enables it to attract and repel light substances, and the same effect may be produced by rubbing a vulcanite comb on the sleeve of a coat.

If we examine the *conditions of this* experiment by the light of advanced knowledge, we find they consist in the presence of (1) a dielectric in contact with (2) the conducting body of the operator; (3) another electric in similar contact; (4) mechanical motion, or friction of the two electrics; (that is, a supply of energy); and (5) separation of them when the friction is ended. These conditions include every instrument devised for developing electricity by friction, and they may be applied in the simplest form.

28. THE ELECTROPHORUS.—This is the simplest source of electricity next to the mere rod; it has many forms, but its principles are the same as that of the rubbed rod. A common form consists of a circular tin dish filled with sulphur or any resinous substance. A cheap electric may be made with 8 parts of resin, 1 of shellac, and 1 of Venice turpentine or wax, well melted together and run into the dish; a hook is soldered to the dish, for convenience of attaching a conductor. The dish forms the conductor from the dielectric to the earth, as the books tell us, but really to the body of the operator, who rubs the face of the disc with a piece of flannel or fur, or a silk pad covered with electric amalgam. A means of collecting the electricity from the surface is now required, and this is the cover, consisting of a piece of sheet metal, or smooth wood covered with tinfoil, and having a handle of glass or well-baked and varnished wood.

A disc of sheet ebonite coated on one side with tinfoil forms an excellent electrophorous.

29. It is desirable here to remark that glass, though one of the best non-conductors, condenses moisture on its surface, and becomes a conductor. Therefore, those parts of electrical instruments which are made of glass, should, where possible, be covered with a varnish which has less attraction for moisture. This applies to the handle of the electrophorus cover, legs of insulating apparatus, necks of Leyden jars, and those parts of electrical machines which have not to be rubbed. The varnish should be moderately thin, so as to require several coats, rather than one of a thick varnish; 1 lb. of shellac, dissolved in 1 pint of polisher's finish, forms a tough coherent surface, and adheres strongly if the glass be warmed before applying it.

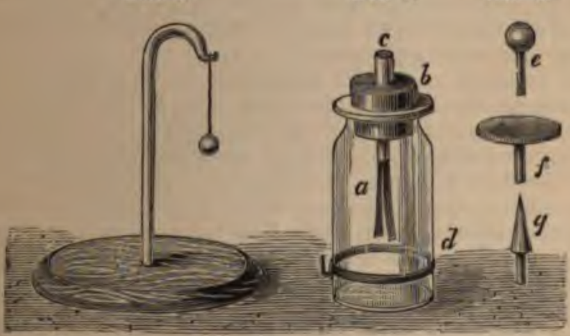
Ebonite also requires similar treatment owing to the formation of an acid upon it: melted paraffin is useful as a coating rubbed over ebonite.

The best mode of ensuring perfect insulation is a modification of Johnson and Phillip's liquid insulator, as made for telegraph lines, and also in the form of feet or stands for batteries. The *stem of a support*, such as Fig. 6, instead of being fixed to a stand, should be inserted in a glass tube which can contain an insulating liquid, resisting the deposit of moisture: pure resin oil is found to be perfectly adapted to this purpose, and not volatile; a shield should be provided to keep dirt out.

Also in electrical experiments, it is desirable to warm the apparatus, and to work in dry and moderately warm air. When the air is moist, success is scarcely to be attained. Moist air is, however, not a conductor, as has long been believed: it is the deposit of moisture on surfaces which causes loss of electric charge.

30. ELECTROSCOPES are instruments for manifesting the presence of electricity. An instrument adapted to varied experiments is described § 33, but Fig. 6 is the simplest form, being a glass rod mounted on a stand, and bent at the top into a hook, from which hang, by silk thread or hair, one or two pith balls. Fig. 7 is a more elaborate instrument; it is a glass bottle; on opposite sides of the inner surface are pasted strips of tinfoil, which are continued to the outside and to a brass ring fitted with a hook for conductors. Through the cork passes a brass tube, closed at the bottom, to which are fixed two strips of gold-leaf. The bottle should be well dried and warmed, and the cork cemented in and coated with shellac varnish; when the loose fittings *e* or *g* (Fig. 8) are inserted, it is a simple gold-leaf electroscope; *f* is a metal plate covered with a coating of shellac on its upper face, and when this is fitted to the instrument and an exactly similar plate with an insulating handle placed upon it, we have a condensing electroscope. The lower plate is connected to the source and the top of the upper plate touched with a conductor to "earth," such as the finger, just as

FIG. 6. FIG. 7. FIG. 8.



in using the electrophorus and for similar reasons: on removal of this conductor and then the upper plate, a far greater divergence of the leaves is produced than if the source had been connected to them directly.

31. Connected as described, the leaves exhibit the same electricity as the source; the same effect is produced if the upper plate is connected to the source, but then the leaves exhibit the opposite condition. The leaves diverge alike for positive or negative charges, but the nature of the charge is readily ascertained by rubbing a piece of ebonite, and approaching it to the instrument; if this is charged with +, the leaves fall together; if with − the divergence increases; both effects are temporary, and cease when the ebonite is withdrawn; with excited glass the action would be reversed. A similar process is useful in testing feeble charges; if the electroscope is charged slightly with + electricity, when approached by a + charged body the leaves will increase in divergence; on approaching a − body they will collapse.

These instruments only indicate the presence of electricity; to measure it electrometers are employed as described § 74.

32. One of our standard electrical works says (and it is just what all say), "*Vitreous* substances, such as glass, become electrical by being rubbed with certain other substances; in this state they attract light bodies. *Resinous* substances, such as sealing-wax and guttapercha, become also electrical when rubbed with certain other substances; in this state *they* also attract light substances. Bodies which have been once attracted by excited glass or excited resin will not be attracted by the same substance again until they have touched some body in communication with the earth, but will be repelled. A body which, having been attracted by an excited *vitreous* substance and is then *repelled* by it, is *attracted* by an excited *resinous* substance; so also a body which is repelled by an excited *resinous* substance is attracted by an excited *vitreous* substance."

These statements are received as absolute truth by most electricians, and upon them the fluid theories of electricity are based; and yet there is scarcely a truth in them which is not overweighted by an error, and the simplest facts are misinterpreted.*

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* One of the critics of the first edition of this work said, as to this statement, that he was not aware "that the author had done anything to prove that he is able to sit in judgment on the intellectual giants among modern men of science. Mere off-hand condemnation of the laborious work of men like Sir W. Thomson and Prof. Clerk Maxwell cannot for one moment be tolerated." Those eminent *writers were neither* condemned nor named, and science would make poor

33. Let us examine this matter of attraction and repulsion, by the aid of the simplest experiments. Our vitreous substance may be a piece of stout glass tube, and our resinous substance a piece of ebonite; the back of a comb will do, or a slip cut out of a thick sheet. A silk handkerchief, or a piece of flannel will serve as exciter.

A convenient electroscope consists of a tube of glass upon a foot; in the tube is placed a brass rod with a tube across its upper end, in which slides a wire, one end finished with a lump of guttapercha or glass bead, and the other with a hook, for the pith ball or balls. Let a pith ball be suspended by a dry hair or silk fibre, and the excited electric be presented; the ball will be first strongly attracted, and then steadily repelled; but if an excited electric of the opposite order be presented it will attract the ball, and then, if capable of reversing its charge, will repel it. Hence it is stated, as a fundamental law, that bodies similarly electrified repel each other, *which is not true*, so stated. If an excited electric be placed apart from all surrounding bodies, in a dusty atmosphere and in a beam of light, it will be seen to attract the floating particles and hold them without at all repelling them after contact. If the supposed repulsion really existed, it is obvious that these bodies, which are of course similarly electrified by contact with

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progress if a thinker is to be debarred from the examination of theoretical principles advanced by any one, however eminent. However, Clerk Maxwell, in his posthumous work, published in 1881, shows that he was gradually abandoning the scholastic theory of electricity, and would apparently in due time have adopted the very doctrines taught in these pages. In his preface he says, "in the larger treatise, I sometimes made use of methods which I do not think the best in themselves, but without which the student cannot follow the investigations of the founders of the mathematical theory of electricity. I have since become more convinced of the superiority of methods akin to those of Faraday, and have therefore adopted them from the first." The theory advocated in these pages is the direct outcome of Faraday's investigations and teachings, and its method of putting questions to Nature, instead of creating an artificial oracle from mathematical abstractions, is that of Faraday, who never troubled himself as to those formulæ which, as he said, were the affair of the mathematicians. Now what says Clerk Maxwell, as to the movements set up by electricity? He describes the electric field, in which are lines of force, with an electromotive force acting in one direction along those lines; speaking of a suspended pith ball, he says, "it will move under the action of a new force, developed by the action of the electrified ball on the electric condition of the field." "If the charge is positive, the force which acts in the ball is on the whole *from* the positively electrified body and *towards* the negatively electrified walls of the room." Here we have no word about a repulsion between the similar electricities; the explanation of repulsion and of the part played by the connection to "earth" are identical with the views here explained, *which are being* more and more adopted by electricians *and now taught by those who used to oppose* them.

the electric, *could not be held* firmly to it. In fact, the repulsion is only apparent, the real cause of the motion is to be found in the attraction exerted by the surrounding bodies, as will be fully explained as we proceed.

Experiments on attraction and repulsion are endless in variety and interest, but they will not be described here, because they are to be found in most text-books, and because it is not the purpose of this work to go further into the subject of static electricity than is necessary for the examination of its leading principles; those who wish to study it thoroughly can follow the smaller work of Clerk Maxwell, bearing in mind that many of his explanations were written while his mind was in a state of transition. A more exhaustive study of the subject will be found in 'Accumulation and Conduction of Electricity,' by F. C. Webb, a work little known because a full generation ahead of its date of publication.

34. Before entering upon the various theories of the nature of electricity, it should be noted that the common terms of electrical science have grown up from the older theories, and hence we have

$$\left.\begin{matrix}\text{Vitreous}\\ \text{Positive}\\ +\end{matrix}\right\}\text{ and }\left\{\begin{matrix}\text{Resinous}\\ \text{Negative}\\ -\end{matrix}\right\}\text{ Electricity.}$$

Also the words charge, quantity, conduction, accumulation, and distribution, which imply the passage of something having a real separate existence; these and similar terms we are obliged still to use, but the meanings they convey in this work will be defined. The last terms and their signs will be those used, as they are generally known, but they will not be used as implying an excess or deficiency of a fluid, but as expressing opposite polarities of matter.

35. THE TWO-FLUID THEORY.—When it was found that the electric excitement produced on glass was opposite in its nature to that on amber and resins, the earlier experimenters concluded that there were two "fluids" pervading matter; that each of these fluids exerted a strongly repulsive action on its own parts or bodies charged with itself, but that each fluid had a strong attraction for the other, and both a strong attraction for ordinary matter; also, that in the ordinary condition of matter, the two fluids were united in equal proportions, being thus neutralised and adherent to matter. Some have supposed that the two fluids when thus united constituted another hypo*thetical fluid, caloric,* or heat.

It was supposed that by friction of some substances, thence called electrics, these two fluids were separated, the one remaining on the surface of the electric, the other on the rubber, and that, from these, either could be transferred to insulated bodies, that is, to substances which furnished no pathway along which the disunited fluids could find a way to the reunion intensely sought by both. Hence, when a charged body or an excited electric is presented to a light movable body, the latter is drawn towards it by the attraction of the fluid for matter; as soon as the charge is equally divided, the self-repulsive property of the fluid causes the bodies to repel each other; and then if a body similarly charged with the other fluid is within reach, attraction occurs, the fluids reunite, with a spark if the quantity and tension are great, and resume their usual neutral state. But if there is no such oppositely charged body accessible, any body in conducting connection with the earth will enable the charge to dissipate itself, as some say, because the earth is a comparatively infinite reservoir of both fluids, but more simply and more in accordance with the theory itself, because it presents an unlimited surface and body of matter; and the fluid distributing itself over all surfaces and matter to which it has a conducting path, the charge, which is great upon the small surface of the electrified body, becomes nothing when it has the whole earth to spread itself over. This hypothesis was built upon the phenomena of frictional electricity, and of these it furnishes a moderately satisfactory explanation.

36. THE ONE-FLUID THEORY was devised by Franklin, as more simple than the other. He supposed that there was one electric fluid pervading all matter, possessing a strong attraction for matter, but being strongly self-repulsive: matter in its ordinary state has in connection with it so much fluid as satisfies the mutual attractions, but when certain bodies (electrics) are rubbed, some absorb part of the electricity from the rubber, and thus become *positively* charged with this overplus; others part with their proper electricity to the rubber, and thus remain themselves *negatively* charged. As with the other theory, the earth is supposed to receive the electricity driven off, or to supply any quantity of it when needed. This theory also explains the ordinary phenomena of static electricity, and on it Berzelius built his electro-chemical theory, which ruled chemical science for many years, treating the relative affinities of different substances as due to the relative proportions of electricity belonging to them.

37. These theories were devised when only the static phenomena of electricity were known; but, when dynamic electricity

was discovered by Galvani and Volta, it was found that they failed more and more to explain the new facts. But, even if they furnish a sort of explanation of the simpler static phenomena, a slight examination will show the utter improbability of the "fluid" explanation of even these. The fluids have a strong attraction for each other and for matter, yet the rubbing of two substances together is sufficient to separate the fluids from each other, and from the matter with which they are in quiet union. They have a strong repulsion for themselves, yet in addition to overcoming these attractions, we easily collect these self-repulsive fluids into separate reservoirs. At the instant of doing so these reservoirs are in actual contact, yet the fluids do not reunite there, though they will do so with great violence when again brought into somewhat near neighbourhood, and travel any distance to get the opportunity. In fact, at the point of origin the fluids must actually transform their mutual attractions into repulsions. Looked at thus, it is obvious that such theories could only have been formed in the determination to make some kind of explanation of striking phenomena newly discovered, and that they have held their ground simply from habit and the gradual training of every one's mind to study the phenomena only by means of them.

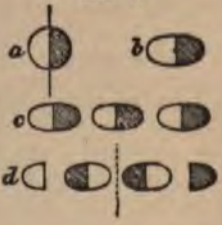
38. THE MOLECULAR THEORY was founded by Faraday in his memorable experiments on induction, but it has since grown with the growth of the other sciences; it is a sequence to the now accepted doctrine of heat being motion, and is intimately connected with the modern doctrines of chemistry. Simply stated it is, that electricity has no existence as an *entity*, but the phenomena are due to properties and motions of the molecules of matter. Of late there has been a tendency to attribute the actions of electricity to motions of the supposed ether (see § 7), which is considered to be in some way condensed upon the molecules: this idea is naturally most favoured by mathematicians, and to all but trained mathematical minds it is nearly incomprehensible, and appears only a modification of the one-fluid theory: if the ether is so condensed, it becomes a part of the molecule and the cause of its actions, and therefore we may proceed to treat the molecules of matter as possessing certain properties now to be studied, leaving in suspense, as beyond our present knowledge, the cause of those properties.

39. Our former consideration of the molecule (§ 11) related to its *chemical* constitution. We have now to examine its *physical* character, *internal*, as regards the manner of its existence and breaking up, and *external*, as to its attractions for *and relations to other* molecules; and we have to consider it as

a body composed of two distinct parts linked together, but acting also as a whole from a common centre. Tyndall's words when describing the actions of light, heat, and pressure on gases, convey the idea very fully :—"Molecules do separate from each other when the external pressure is lessened or removed, but the atoms do not. The reason of this stability is that two forces—the one attractive, and the other repulsive—are in operation between every two atoms, and the position of every atom—its distance from its fellow—is determined by the equilibration of these forces." "The point at which attraction and repulsion are equal to each other is the atom's *position of equilibrium.* If not absolutely cold—and there is no such thing as absolute coldness in our corner of nature—the atoms are always in a state of vibration, their vibrations being executed across their positions of equilibrium."

The idea of a repulsive force is now substituted by that of potential energy, as internal motion, but this does not affect the explanation that the internal attractions of matter draw the atoms together; the forces of heat, &c., as motion, tend to separate them; and (the molecule being constituted by the balance of these forces) additional force tends to separate the atoms, and break up the molecule. We may now simplify our conception by Fig. 9 *a*, in which we represent the two halves of the molecule as vibrating on a central point, or vertical line.

FIG. 9.



Now a force which either intensifies those oscillations, or which sets up a revolution of the entire molecule on the same centre and line, would tend to alter the molecule to Fig. 9 *b*, in which the internal attractions are weakened. If we now conceive a line of such molecules, Fig. 9 *c*, we see that there must come a time when the atomic attractions will be greatly weakened internally and partly exerted on the corresponding or complementary parts of neighbouring molecules. In this state the substance may be said to be *polarized* (§ 15). The degree of this tendency would be called its tension, being the strain upon the attractive forces; as this increases there comes a period when the molecules break up and re-form, as shown in Fig. 9 *d*. This will be a discharge. The extreme atoms here may be considered either as forming parts of a continued chain, or as set free.

40. Faraday's theory of induction by polarization of adjacent molecules, though the origin of this conception, is very different

from it; he treated of the actions of a body charged with electricity, and its mode of action on surrounding bodies, but later discoveries have developed that theory of the *effect* of electricity in the form of charge, into a theory of the *source* or *cause* of electricity itself; which may be thus defined.

Electrical action is developed only when a complete chain of polarized molecules can be formed. When that chain is wholly composed of conducting molecules, dynamic electricity is manifested; when partly composed of non-conducting molecules, we have static electricity.

41. We are now ready to examine the conditions under which, and the reasons why, friction develops electricity; when two solids, or a solid and a liquid, are rubbed together, electricity is developed; gases do not appear to produce this effect, but we need attend now only to the familiar electrical phenomena. We have hitherto treated glass as becoming positive by friction, developing vitreous electricity, but this is not an absolute fact; if, instead of a piece of silk for a rubber, we use a piece of cat's-skin, the glass becomes negative. The following list (given in Ganot's 'Physics') shows the bodies which develop positive electricity in the higher, and negative in the lower in the list, when rubbed together:—

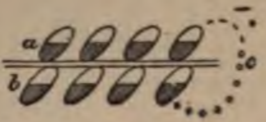
+ Cat's-skin.
Glass.
Ivory.
Silk.
Rock-crystal.
The hand.
Wood.
Sulphur.
Flannel.
Cotton.
Shellac.
Caoutchouc.
Resin.
Guttapercha.
Metals.

This list shows that the nature of the substances in friction governs the result, and probably the most complete examination into this point was made by Coulomb, whose conclusions were, that those bodies whose parts are least disturbed by the friction tend to become positive, particularly if compressed; those which are most disturbed become negative, especially if dilated.

42. This implies that molecular disturbance is the origin of the electricity; and the deduction is very plain, that when two dissimilar substances are rubbed together, a certain amount of adhesion is produced, which is an external attraction, as cohesion is an internal one. This attraction being opposed to the natural state of the bodies, tends to draw the superficial molecules away from their neighbours; the opposing or complementary halves of these tend to unite, while the internal attraction of the molecules is weakened—they are polarized; Fig. 10 conveys an idea of this effect. The superficial molecules react *on their neighbours;* and a complete chain of excited polarized *molecules is formed,* along which is transferred the energy

which but for the friction would have generated increased motion. It does so still, but if there be no resistance it produces that which we see and familiarly call motion; if there is resistance, we have the motion among the molecules, which is electricity, and this again exhausts itself in the vibrations of heat.

Fig. 10



Here we have a theory which unites Static and Dynamic electricity, and explains alike the excitement by friction, chemical action, and heat. All call into action the latent attraction between what for convenience we may call the + and − atoms of *different* molecules, weakening the + and the − attractions *within* the molecules, and setting up a polar chain which can transmit energy entering it at the point of origin, which thus constitutes a source of electromotive force.

43. Now, returning to Fig. 10, let the line of dots *c* represent the molecular chain, variously formed to convey the idea of the different substances which may compose it. When we rub the electric the chain is formed through the body. On separation it completes itself through the air, showing the one hand holding the electric +, and the other hand −. The air space now constitutes a "field of force," traversed by lines of force connecting the surfaces on which the + and − electricities appear to exist. A pith ball or other body approached to either of these surfaces becomes part of that field, is put under stress by those lines, and moves in obedience to the electromotive force, producing the various phenomena of attraction and apparent repulsion.

44. The fundamental laws thus far developed are:—

(1) *Electrified substances attract neutral substances, and then under certain conditions repel them.* They do so by polarizing their molecules, and then, if the electrified body be in a + condition, attracting the − side of the molecules.

(2) *Substances dissimilarly electrified attract each other.* That is, bodies, the external molecules of which present, one their + extremities, the other their − extremities to each other, are mutually attracted by entering a line of force.

(3) *Substances similarly electrified repel each other.* That is, there is no attraction between the two molecules presenting their + or − extremities to each other, and they so move that they may enter a line of force in symmetrical polar order.

These are the ordinary electrical laws (for a scientific *law* merely means the statement of a natural fact), interpreted according to the molecular theory. Their full meaning will be seen when the nature of the "inductive circuit" and the action of a field of electric force have been studied.

45. The action of the electrophorus will exhibit many of the principles of electrical science, though we cannot obtain from it any very striking effects like those of powerful machines. A very convenient and simple form consists of a glass and an ebonite disc (the glass merely for noting differences of action), provided with a cover, and a stand of wood somewhat larger than the discs. The wood should be thoroughly baked, well covered with shellac varnish, and supported by three feet of ebonite rod or guttapercha to form an insulating stand. The upper face should be covered all over with tinfoil, connected to a small hook or ball screwed into one side for attaching conductors to. On the edge of the face should be three studs or pieces of wood to hold the disc in its place when rubbed.

46. These stands serve also for many experimental purposes, but as wood conducts electricity, on account of the moisture it contains, for all electrical purposes it should be slowly and thoroughly baked without scorching, put into melted paraffin while hot, and kept there as long as any bubbling continues; it should then be removed, and, as it cools, be dipped several times so that the grain and pores of the wood become thoroughly filled up: in this state, wood is a good insulator. Paper can be prepared in a similar manner.

For adjustable stands, a rod of wood can be used, attached to a foot; pieces of brass tubing filled with a cork bored to fit the rod, will slide to required height and carry cross rods on which similar corked tubes will give any desired angular adjustment: such easily constructed holders are very useful for chemical and other uses. A slab of recently melted paraffin makes an excellent insulator, while such a stand as just described, or a sheet of tin, replaces the "earth" so constantly referred to in electrical books.

47. To use the apparatus for examining the principles of the electrophorus, place the ebonite disc on the stand, rub it well with a silk handkerchief and apply to its face a *proof plane.* This is simply a miniature cover, a piece of metal or wood covered with foil, and mounted on a glass handle; it is well to have a variety of these of various forms and sizes, providing them with a piece of tube or a wire at the back, to slip on a glass handle or a stick of shellac. On touching the ebonite with this and presenting it to the pith ball electroscope it will be found that there is no action. Now this may arise from two *causes, and therefore* the principle must be examined.

48. It is generally considered that when an insulated body touches a *charged* one, the two become one, as far as the electricity is concerned; that this distributes itself over both surfaces, and when these are separated each is supposed to retain its proportionate share of the "fluid." The proof plane is so employed in many cases, but it acts differently on the electrophorus, a fact which throws great light upon the true nature of "Charge." The electrophorus is apparently, to all intents, a charged body, for its face, if resinous, is in a purely negative or − state, yet if we apply the proof plane and remove it we shall only discover a faint charge. In order to obtain electricity on the plane we must touch its upper face with a conducting body, in what is called "connection to earth"; practically the operator's finger will serve, but for the sake of theory the connection should be a piece of wire attached to a chain, which drops on the floor, or is hung to a gas-pipe: with our insulated stand, we at once see that connection to its conducting face, which is in contact with the back of the electric disc, gives exactly the same result as connection to "earth"—it in fact fulfils the conditions of § 27.

49. This is also the way in which the electrophorus is used for any purpose; in order to charge it by friction, the back of it, whether this be a metal dish in which it is cast or the foil on the back of a disc lying on the stand, must be "connected to earth," or, in reality, *to the rubber*; without this no charge is generated; but this circuit being made, it is excited by friction, the cover placed on its face and touched on the upper surface with the finger, to make connection to the back; the cover when now raised is found to be charged, and sparks may be drawn from it. The instrument, when excited, will retain its powers for a long time if the cover be placed on it; in a dry air it may retain its charge for days or weeks, ready to give a spark without fresh excitement. In this way electric gas-lighters are made.

50. A reference to Fig. 10, p. 27, will explain the conditions. The lower line of molecules *b* may represent the excited disc, and the upper row *a*, the rubber during excitement, and the cover when in use. The mass of the dielectric becomes polarized, and the essential property of these dielectrics is to retain this condition of *stress* in which energy is so charged upon their molecules as to constitute a field of force within them, having a strong resemblance to the magnetic conditions. In order to set up this field of force and state of stress, the primary condition is that there shall be a completed circuit (§ 27). If the *connecting chain c*, Fig. 10, is removed, the

electrophorus which it represents will receive no electric charge, but friction would heat it: if we connect the sole plate to earth, with which the rubber is also connected through the body of the operator, we have electricity instead of heat; that is to say, we have *potential energy* stored as stress in the molecules of the dielectric, ready to produce the phenomena of electricity, when the proper conditions are present. If we now place the cover on the face, without connecting it to the back, the cover only replaces a stratum of air; its conditions are the same as those of a cylinder brought within the "inductive field" of a charged body, so that it is "polarized," + on one side and equally − on the other. But if we close the circuit *c*, Fig. 10, new conditions arise; if the cover were in perfect contact with the dielectric, discharge would occur, for then the conditions would be those of the Leyden jar. But in fact the cover only touches a few parts of the surface; the conditions are more comparable with those of a magnet when its armature is placed on its poles; the consequence is that when the circuit is broken, the cover assumes a state *opposite* to that of the dielectric, because now it really continues the polar order of the other side of the dielectric to which it had been connected. The old explanation was that the − charge on the face *induced* a + charge on the cover as it approached, and that the corresponding − of the cover went away into the earth, and then the opposing + and − charges *bound* or *dissimulated* each other, all which is needless complication. There is an attraction between face and cover, as there is between magnet and armature, in which latter case we have what might equally be called, bound or dissimulated magnetism; in both cases also the removal of the attracted body, against the force of attraction, restores the energy expended in setting up the polar force. The cover on removal has an apparent charge of free + electricity; but in fact, as long as it lies on the plate it is in the line of the external circuit of the plate to its sole, and on removal, it divides that external field, setting up fresh lines of force to all surrounding objects, until it approaches near enough to some object in which these lines of force can concentrate, when discharge of this local field occurs as a spark. The required connection to the other side of the dielectric is frequently made by a pin coming through the mass of the electrophorus, with which the cover makes contact at once without any special process: this disposes of any theory calling forth the agency of the "earth" as a reservoir and sink of electricity, because the instrument acts just as perfectly when insulated as when connected to earth; so also do electrical machines when their rubbers are insulated and connected to the outer coating of a Leyden jar while the inner coating is charged from the prime conductor.

51. In working for discovery it is requisite to experiment first and then seek the interpretation, and this is a good mode of instruction also; but, on the other hand, an experiment, and, still more, a description of one, is far more intelligently studied when its object is understood, so this subject has been discussed more fully than usual in text-books. In seeking out principles, the simplest instruments and experiments teach more than more elaborate ones, because these often introduce complications which may put out of view the most central and essential points. They also lead up gradually to more extensive studies, and thus, §§ 49–50 are an anticipatory outline of what is yet to be studied under more general conditions.

52. The earlier electricians, attracted by the more obvious phenomena, missed the principle underlying them. Therefore, the expressions of most electrical writers are such as to justify the notion that either positive or negative electricity is capable of separate existence, isolated from, and independent of, its opposite. Yet all now admit this general law.

(4) *One electricity can never be produced without producing at the same time an equal quantity of the other.*

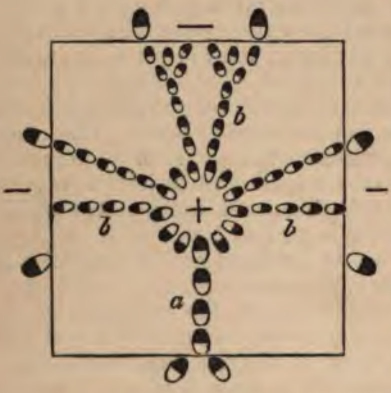
Thus, in friction, if the electric be +, the rubber is −; so also in a battery, one extremity is +, the other −; and in a Leyden jar if the inner coating is positive, the outer is negative. All theories include this law, because it is a simple fact; but it is an inevitable consequence of the molecular theory, for the molecules necessarily have two opposite sides, and the reactions of these sides are the causes of the phenomena. But the fluid theories assume that, having produced separation of the two electricities, one of them may be dismissed into the earth as the common reservoir, or infinite conducting surface, leaving the other free and isolated.

53. EARTH CONNECTION.—In working an electrical machine, we must lead a chain from the rubber to the floor or gas-pipe, or we obtain only a slight effect. Hence the idea that we make a connection with the mass or surface of the earth itself. But we learn from § 50 that we really form a connection, by means of moderately good conductors, with *the walls of the room*. The room becomes, in fact, a large Leyden jar, of which the dielectric *air* represents the glass. The charged bodies or prime conductor form the inner coating, and the walls of the room the outer coating, with lines of force connecting them. But the so-called "charge" on the small surface is very apparent, while the equal charge *on the walls, being* of much lower density, does

not manifest its presence. The molecular theory does away altogether with the supposed function of the earth, which really acts simply as any other conductor does in dynamic electricity, and has nothing at all to do with static electricity. The "earth" connection should be regarded as a zero or binding screw common to all the circuits which may be connected to it.

54. SURROUNDING SURFACES.—Fig. 11 shows + the charged body, with its molecules presenting their + ends outwards; *a* is the earth connection conveying the polarization to the walls of the room, which are thus rendered –, and *b b* are the molecules of air forming the lines of force or polar chains.

FIG. 11.



This explains why any one near an electrical machine in action experiences a peculiar tingling sensation. His body is in the path of polarization, and as he is a better conductor than the air, a good part of the circuit is concentrated in his body. The small superficial hairs rise and point on one side to the nearest wall or other bodies, and on the other, with still greater intensity, to the machine. This happens even if he is insulated, but if he is in connection with the floor, the nearer he stands to the machine the more he represents the outer coating. He is, in fact, electrified, not, as might be supposed, by the machine and with the electricity of the conductor, but with the opposite, because he completes the polarized chain, while, if insulated, he will be + on one side and – on the other. Hence we find,

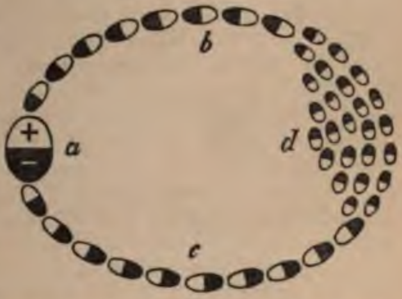
(5) *The other electricity is, in equal quantity, distributed over another surface separated from the first by a dielectric in which there exists a field of force due to these two equal opposite charges.*

Thus, when another insulated body touches the first, it does not, as generally supposed, take part of its free electricity. It simply enlarges the "inner coating," and, of course, in doing so proportionately lowers the "density" of the charge, that is, the number of lines of force upon a given area.

55. INDUCTION.—This term is so frequently employed in electricity that it is necessary to define fully the idea it is intended to convey. Generally it may be said, that any molecule when "polarized" *induces* all others within its influence to follow its example, that is to say, employing the true meaning of the word, it *draws them* into the same systematic order: in like manner a magnet *induces* magnetism in neighbouring bodies susceptible of becoming magnetic, and an electric current *induces* a current in neighbouring conductors. This results from the constitution of the molecule, § 39, when under the influence of "polarization," which diverts part of its energy externally.

In Fig. 12, *a* is the primary molecule, whence the polarizing force acts in both directions, and on each side, *inducing* its neighbour to turn towards it the side for which it has the greater attraction. Thus its + side acts on the molecules *b* and its − on the molecules *c*, seeking on each side the shortest course to complete its chain. The collection of molecules *d* represents the passage from a good conductor into a dielectric, as from a charged surface into air.

Fig. 12.



But the term "induction" has also been applied to what would be a second production of electricity.

Since it has been recognized that, on bringing a surface near to a charged body, a charge of opposite name appears upon it, this charge is commonly said to be "induced": so also is the charge on the surrounding walls said to be "induced" by the charged body. This is a consequence of the error as to the action of the earth; first we are supposed to separate neutral (+ −) and place + on the body, while driving − into the earth, where it departs to "somewhere about Australia" as one writer explains: but then this +, objecting probably to its solitary existence, "induces" a − charge to keep it company on the walls; whether it is the same − come back from Australia is not explained. But this is not induction; it is the primary act of charge—a dual action.

56. It is desirable to describe now, the more powerful sources of *electricity and the means of* measuring it, before further

following out the theoretical principles: but I do not propose to occupy space by describing instruments which are fully described in all the text-books; it is not likely that this will be the only book accessible, and therefore it is better service to my readers to refer them to others as to such universal and simple matters, and occupy space here with subjects they do not find in every other book. When dealing with such subjects, it is because they form part of a necessary line of examination, or in order to furnish information which may assist readers in making the instruments for themselves.

Electrical machines are of two distinct classes:—

(1) *Frictional machines*, in which the electric is constantly excited by friction and as constantly discharged into a reservoir of force; this class includes the plate and cylinder machines.

(2) *Induction machines*, which operate on the principles of the electrophorus, accumulating a succession of actions till a feeble initial charge attains the full power.

57. FRICTIONAL MACHINES.—The principles of the frictional machine are those laid down § 27. There is (1) The electric to be excited, the plate or cylinder. (2) The exciter or rubber. (3) The mechanical motion generating friction and supplying energy. (4) The circuit of polarization, which here includes the "separation," because part of it must be non-conducting. (5) The reservoir of force—the prime conductor, as it is called, but which is strictly a part of the circuit of polarization, though most conveniently considered separately.

The electric is usually glass. Guttapercha may be used, and has been employed in the form of a band stretched between pulleys: electrical machines have been thus generated unintentionally in manufactories, and fires have been caused by sparks given off from belts.

The best electric is ebonite, but its surface deteriorates after continued friction. It is subject also to the formation of a film of sulphuric acid upon its surface, owing to the ozone produced when the machine is worked, which is the cause of the peculiar smell perceived.

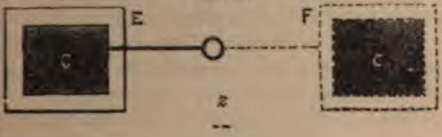
The hardest glass, containing most silica, is best; crown glass, such as window sheets are made of, or that from which common pale green coloured bottles are made, is better than flint-glass. A cylinder machine may be made of a large bottle, if one is selected with straight sides and polished surface; a rough surface does not generate electricity well, as only the salient points come in contact with the rubber.

These machines are so little used, now that the more effective *"Influence machines"* are so much improved, that it is needless to occupy space with details of construction which can be found in any of the older electrical books.

58. **Induction Machines.**—The second great division of electrical machines is based upon the principle of the electrophorus; there is a small initial charge, from which a moving plate, representing the cover, takes a succession of charges, transferring them to a condenser or conductor, which in turn reacts upon the original charge and gradually raises it to a high tension. In these instruments, although there is no direct friction, there is set up a resistance to motion by these electrical actions, which transform mechanical energy into electrical energy with all its effects.

The original of all the various forms was Varley's multiplier, in which was, for the first time, applied the principle of "accumulation," which, applied also by Mr. Varley to the magneto-electric machine, is the foundation of the powerful generators of current electricity now in use. In the generators both of static and dynamic electricity, the principle is that a small initial charge can be used to convert mechanical energy into electrical energy, and to develop a high force. The principle may be understood by means of Fig. 13, E F are plates of metal (which in the instrument were arranged in a row) in front of which the plate C (which corresponds to the electrophorus cover) can rotate. The plate is carried on an insulating arm, but with appliances to connect it at proper intervals to "earth" which is really a zero point indicated by z, to which C can be connected at the required moments, as also can other plates similar to E F; a small charge, such as may be obtained by rubbing a piece of ebonite, is put upon E, which represents the electrophorus face, which we will consider as being in a + condition. C being connected to z, which represents the back or sole of the electrophorus at this stage, of course takes a − charge equal to the + on E. C is now moved, breaking connection with z, and carries its − charge over to F, with which it makes momentary contact; contact with z following, a + charge is induced on C, which it in like manner carries on and adds to that on E. In the actual instrument, of course, the

Fig. 13.



charges which are induced upon C involve a corresponding opposite quantity transferred, by means of a temporary connection to z, to another set of plates similar to E F, in which the same series of operations are carried on. At length the charge rises to the full "potential" of which the insulation of the instrument admits, and then the electricity overflows into the external circuit.

These principles have been applied to a variety of machines constructed by Holz, Töpler, Voss, and others, and a very small form is employed in the elaborate electrometers on the quadrant principle of Sir W. Thomson, § 75, for the purpose of maintaining the electric charge upon the moving system. These machines are fully described in most of the text-books of electricity and of physics, so that I will only give a full description of the latest and probably the most satisfactory form, which is easily made by any one with moderate skill.

59. THE WIMSHURST MACHINE.—The great distinction between this and its predecessors, the Holz, Carré, Voss, and other Induction or Influence machines, is that both plates rotate in opposite directions: the effect is that while in the older machines one plate was the *Inducer*, corresponding to the field-magnets of dynamo machines, and the other the *induced*, corresponding to their armature, here each plate plays alternately each part, as the sectors change relations; also the speed and the rate of reaction are practically doubled: hence there is more certainty of excitement, a more rapid attainment of full power, and less liability to loss by moisture in the air.

Fig. 14 will explain the construction if the principles governing each part are thoroughly understood. The frame may be made of any hard wood, which may be treated as in § 29: it is shown standing on feet high enough to allow the driving wheels to be mounted under it, working in slots. These two wheels are attached to an axis which may be of hard wood or of metal, fitted with an ordinary driving handle; they should be fixed as far from the plates as the stand allows, at least 3 inches, and more in proportion to intended length of spark, so as to prevent side discharges.

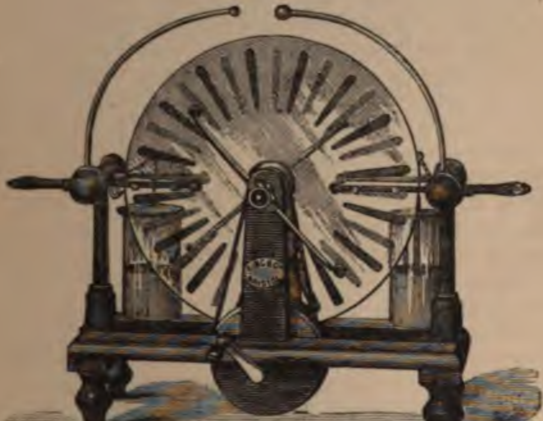
60. The *standards* should be more conical than is shown, to give steadiness, and should be very carefully morticed into the stand: the tops should be made removable, so as to form clamp bearings for the spindle, as this facilitates the removal of the plates; but mere holes are commonly used to place the spindle in, and they should be exactly level, and of such size as to grip the spindle firmly.

61. The *spindle* is best made of steel wire or rod ½ inch thick,

which is obtainable straight and polished; it should project half an inch or so beyond the standards to carry the neutralizing rods as shown, and 2 pieces of stout brass tubing fitting freely should be obtained to serve as bushes or bearings.

62. The *bosses* or hubs of the discs are made of hard wood bored to receive the brass tube just mentioned, which should be firmly secured; the length of the bosses should be such as just to run freely and steadily on the spindle, and they should be given an ornamental outline and be fitted at the outer end with driving pulleys about one-third the diameter of those on the driving shaft: V grooves in all the wheels receive driving bands of round leather, such as are used in sewing machines. The front one simply runs over the pulleys, while the back one is crossed so as to drive the discs in opposite directions; the ends of the bands should be cut sloping, placed on each other. with a little glue or coaguline between, and sewn together so as to give a smooth joint and avoid jerks in driving.

FIG. 14.



The inner end of the boss should be turned off so as to form a flange, to receive the disc, of sufficient depth to enable the glass to be firmly held.

63. The *discs* should be made of good window-glass, selected perfectly flat, 15 *ounce glass is thick* enough up to 18-inch *discs; it is desirable to test its* electrical character for ready

exciting and retaining power, as glass differs much in these respects, and well-constructed machines have failed to act, merely because the glass was not good electrically.

A hole about an inch across should be cut in the centre of the disc to fit on the flange of the boss, to which it should be attached by coaguline or the cement used for the tyres of bicycles, and it is an advantage to make the bosses short enough to allow a disc of ebonite or vulcanized fibre to be cemented over the glass and end of boss, with small screws entering the boss: a couple of small washers of vulcanized fibre of suitable thickness, on the middle of the spindle, will adjust the distance of the plates and diminish friction in running.

A safer way of mounting is to make the central hole larger than the boss, to turn a flanged washer of vulcanized fibre to fit the hole in the glass, and after the two have been cemented together, add the inner covering disc; in this way the attachment to the boss is made with the fibre and there is no risk of splitting the disc. *Other materials* may be used; ebonite makes a good disc, but with the defects mentioned § 57. Brown paper board, well dried, paraffined and varnished, may be used; but mica has been tried and does not answer: stiffness in the material is essential, as, if flexible, the two discs draw together on the vertical line where their electrical states are opposite, and separate on the horizontal line where they are under similar electric conditions.

The discs should be warmed and coated with shellac varnish, which is best applied by rotating the plate on an upright rod to fit the boss, using a large flat brush charged with varnish enough to coat the whole of one side of the disc: the heating is best effected by an iron plate just below the disc, with a Bunsen burner or two below the plate. This gives equal heating without risk of splitting the glass.

64. The *sectors* are made of stout tin-foil, but soft white metal or latten brass may be used. They should be cut all alike by means of a templet of sheet tin. Their length may be somewhat less than one-third the diameter of the disc; all their corners should be rounded off, and they should be mounted on true radii and exactly equidistant, so that those on the two discs exactly correspond in all positions. The easiest method of mounting is to carefully draw the whole disc on a sheet of cardboard, with circles showing the inner and outer bounds of the sectors and disc; then, placing the disc with its inner face on this, attach the sectors, which may be fixed by coating them with shellac varnish, and applying them to the glass when nearly dry and just fit to adhere. When fixed, a ring of varnish should be run

over the ends, or over the whole disc, except a circle under the contact brushes.

The sectors are generally made out of flat metal, but probably it would be an improvement to raise a ridge or button to make contact with the brushes, which could be done by cementing a suitably formed piece of metal on the disc, and embossing the foil on a wooden or metal mould to fit it.

The number of sectors varies with the effect desired; with a large number the machine is more certainly self-charging, but length of spark is obtained by reducing the number; from 12 to 16 is the range for a disc of 16 or 18 inches.

65. *The neutralizing brushes* are made of say 10 very fine wires, soft but elastic, let into holes drilled into the ends of the bent rods, or mounted in very small brass tubes sliding in holes in the ends of straight rods, which will enable the distance to be adjusted exactly to make contact. The rods may be roughly made of brass wire twisted into a helix of 3 or 4 turns at the middle, to clasp the spindle spring tight, and in like manner at the ends to hold the brushes; or they may be more massively made of thicker rod fitted to a tube sliding firmly on the spindle. Their position may be varied according to working conditions, but the front and back rods must be at right angles, and the 4 brushes make contact with their sectors at the same time, and care should be taken that all the wires of the brushes do their work, and do not point away from the line of contact.

66. The *collectors* or *prime conductors* are balls or cylinders with rounded ends, made of brass or of wood covered with foil or gold leaf. They are mounted on insulating stems of glass or ebonite, or as described § 29; in some cases the Leyden jars are used to form the supports; the collecting combs may be formed of U-shaped rods, or in separate rods, extending the length of the sectors and furnished with a row of sharp points extending to within one-eighth of an inch of the discs. The ends of the rods should terminate in balls, and it is an advantage to enclose them in an ebonite or guttapercha shield, like a >, extending as far as the points.

The *discharging rods* are shown in Fig. 14, as mounted upon the prime conductors, in which they turn so as to control the sparking distance; but they may be mounted as rods sliding on balls at the ends of the prime conductors, or they may be mounted on a discharging table wholly detached from the machine, and electrically connected to the prime conductors by flexible wires cased in guttapercha or indiarubber tubes.

One of the prime conductors is in a + state, and the other −, and the *balls on the discharging* rods should differ in size, the constant for all speeds of rotation; this latter seems doubtful. It was also found that the resistance was nearly inversely proportional to the speed of rotation, being 2810 megohms at 120 per minute, and 646 megohms at 450 revolutions; this also seems doubtful. It may be questioned whether the ordinary ideas of electromotive-force and resistance are at all applicable in this case; whether the current is not a mere succession of molecular impulses, the electromotive-force of which is controlled by the conditions of the circuit. This would result in a current proportional to rate of rotation, for which the resistance and the electromotive-force might be both really constant; that is, the resistance cannot be calculated by Ohm's formula, and the electromotive-force varies only as to the period during which it is effective.

72. ELECTROMETERS.—The instruments described § 30 only indicate the presence of electricity; they do not distinguish it as + or −, and only give a rough indication of its degree; but to get accurate information, something more exact is needed before studying the actions of electricity.

Henley's Quadrant is scarcely more than an electroscope, but is easily made, and useful for indicating high charges, as for attaching to the conductor of a machine at work. It is a wire, carrying a plate of ivory or card, upon which a quarter circle of degrees is drawn; a pith ball hangs by a fine thread from the centre of the circle. The wire should be curved and fitted with a ball, against which the movable one will rest, with its thread cutting the vertical line of the quadrant. The ball is driven out to an extent dependent on its weight and the potential of the charge, in ratio of the tangent of the angle.

Harris's is a more delicate modification, in which a wire is attached to the centre of a circle carried by the conducting wire, in such a way as to arrange a ball at each of its ends on opposite sides of the zero line; the moving system is a wire or a straw with a ball at each end, pivoted on a centre pin, so that it can rotate; in this case there is not the whole weight of the one ball to raise, but only so much as the lower part exceeds the upper in weight.

73. COULOMB'S TORSION ELECTROMETER.—This instrument, by which the laws of attraction and repulsion were fully examined, is described in most of the older works, but is little used now. It consists of a glass cylinder with a circle of degrees marked around it; a cover of wood carries in its centre a glass tube, on the top of which is another loose cover, also graduated; from this hangs a silk or glass thread carrying a stirrup of paper, in which can be placed a magnet, or a rod of shellac carrying pith balls at its ends, one of which is gilt. A hole in the cover

allows a similar rod with a gilt ball of same size (or a bar magnet, for magnetic experiments) to be inserted, so as to make contact with the suspended ball, when this is opposite the zero of graduation. At first attraction, and then repulsion occurs, which is then resisted so as to reduce it to a fixed degree, by turning the upper cover carrying the fibre; suppose the angle of repulsion be 36°, and it is required to reduce it to 18°, and that the upper pointer has to traverse 126° to effect this, $126 + 18 = 144°$ is the angle of torsion, and gives the measure of the charge in the terms of the particular instrument.

74. Balance Electrometer.—Sir W. Harris devised an apparatus which is an ordinary balance, one of the pans of which is a disc, below which is an insulated disc of the same size, which is charged from the prime conductor, and the attractive force at varying distances may be thus weighed.

Sir W. Thomson has modified this by adding a large guard ring outside the moving plate, to do away with the effect of the unequal distribution at the edges. The moving disc is attached to a balance arm by wires, so that it plays in the middle of the large fixed guard ring, also electrically connected to the same source; underneath is a plate, as large as the ring, connected to the opposing conductor, either direct, or through "earth."

Measurement is obtained either by actually weighing the attraction, or by altering the height of the lower plate, so as to vary the distance: the position of equilibrium is with the lower face of the disc exactly level with that of the ring.

75. Thomson's Quadrant Electrometer.—This consists essentially of a circular plate of brass, out of which is cut a central hole, and then two spaces which divide it into four equal quadrants, supported on insulating stems in a true plane; these are connected by wires into pairs crosswise, and each pair to a terminal screw by which they can be placed in any external circuit to be tested, which will render one pair + and the other − to a degree corresponding to the difference of potential, or electromotive-force existing in that circuit.

76. A dumb-bell shaped plate of very light aluminium is suspended exactly over the dividing line, so as to lie in the field set up between the two pairs of quadrants; if a + electric charge is given to this plate, it will remain undisturbed if no electric tension exists between the quadrants; but if there be any, it will be deflected over to the quadrants in a − condition, to a degree controlled by—

1. The difference of potential set up in the pairs of quadrants;
2. *The degree of charge* given to the needle;
3. *The resistance offered* by the suspension.

77. The needle is usually carried by an aluminium wire, upon which is also fixed a small mirror, which gives the readings by a lamp and scale, exactly as in the reflecting galvanometer to be described in the chapter on Measurement. It may be suspended by a single fibre of silk or glass, in which case a small magnet is attached to the mirror and a controlling magnet carried by the supporting tube, as in the galvanometer; or it may be carried by a bifilar suspension, consisting of two fibres attached to a short rod on the central wire, and going up through a tube to a support, as in the torsion instrument, § 73. This support may be of varying complexity to admit of adjustment, by tightening one or both fibres, or of controlling their distance apart.

78. This being the fundamental description, the construction may vary according to the delicacy desired and the funds available. The mere plate of quadrants may be exchanged for a double plate in a ring, so as to form a chamber in which the needle floats.

In Edelmann's construction the flat discs are replaced by a vertical cylinder cut into four segments, and the needle is similarly made of two vertical segments of a cylinder fixed together by wires. For cheapness and ease of construction by amateurs, metal might be replaced by thin card or mica gilt.

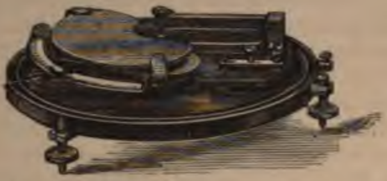
79. The charge may be given to the needle in various ways; it is usually given by means of a Leyden jar connected to a vessel of sulphuric acid under the disc, into which a small platinum wire attached to the needle dips. In the more elaborate instruments this Leyden jar forms the basis of the instrument, and is made of an inverted glass shade, the outer part of the globe of which is coated with foil, while strong sulphuric acid forms the inner coating, and also serves to dry the air within the instrument. An ebonite cover carries the quadrants, supported below it, and the other fittings above.

A *replenisher* is used to maintain the charge, which is really a small influence machine; and an *indicator* of the degree of charge is also employed, which is a small balance electrometer of type § 74. These appliances make the instrument "absolute," that is to say, its readings are not merely proportional, but their actual value in units of measurement can be ascertained when once the intensity of the electric field produced in the indicator is known; this can be measured by giving a known difference of potential to the quadrant system.

80. WRIGHT's is a modification, useful in many cases, which is employed at the Brighton Lighting Station. It consists of a disc of ebonite on 3 levelling screws, carrying on one side a pair

of kidney-shaped plates, forming a conical-shaped chamber in which the needle plays: the needle is a disc mounted on a light rod very delicately pivoted by an axis slightly inclined from the vertical, as also is the chamber in which the needle plays. The needle has a light non-metallic pointer extending beyond the chamber, and playing over a scale, the zero of which is at the wider end of the chamber, which is also the lower. When the chamber and the needle are connected to the two parts to be tested, an attraction is set up by the narrower part of the chamber, which attracts the needle into it against gravitation, the degree of which resistance depends on the inclination given to the system, and may also be controlled by a counterpoise carried on the further arm of the needle. Fig. 15 will explain the construction.

Fig. 15.



81. Bohnenberger's Electroscope has the advantage of indicating the + or − nature of the charge: it consists of two conductors maintained at equal opposite polarities. Between them hangs a gold leaf, or a wire with a gilt pith ball, suspended to a knob from which it can be charged with the electricity to be examined, and which causes it to be attracted towards the oppositely charged conductor: a scale can be placed behind so as to read the angle as in other instruments.

In the original instrument the charge of the two conductors was maintained by means of a "dry pile," but any constant source, such as a series of small galvanic cells, can be used.

82. Dry Piles.—The name is erroneous, because they are to all intents galvanic batteries of enormous resistance, developing high potential, and not meant to generate a current: but they work purely by chemical action due to the moisture contained in them.

Various materials may be used: zinc-foil, paper, and copper-foil pasted together will serve, but the best is composed of zinc- or tin-foil pasted to paper, the other side of which is rubbed with finely powdered oxide of manganese; it is said that honey is better than paste; after drying moderately, a number of such sheets are laid in regular order over each other, and discs punched out of them, say 1 inch in diameter; these are packed, to the number of several hundred pairs, in a dry glass tube fitted *with brass ends tightly* fixed over the discs. Such a rod resembles a magnet in having polar ends, and would manifest the same lines of force as the bar magnet does.

Such piles have a permanent charge, + at one end, – at the other, and will act upon electroscopes; or if formed like a horseshoe magnet, with a ball or gold leaf suspended between the poles, will maintain a steady vibration of this, ringing a bell, &c., for years.

But such a use of them eventually destroys their power: it is developing a current from them, which needs a supply of energy; they might, however, prove useful for some experimental work in which a prolonged minute current is desired, as they would require no attention. But their proper use is to maintain a "field of force" between their poles; or to serve as an electric wand or touchstone.

83. THE LEYDEN JAR.—This instrument, accidentally invented without any knowledge of the principles it is dependent on, is a receiver or reservoir of electricity: it was originally considered, and is still often described as though it were a bottle to be filled with one electricity, and provided the true explanation be well understood, some advantage may be obtained from this view. The jar has "capacity" as a bottle has for a gas, and as with a gas, the "quantity" which can be stored in it is proportional to the pressure and also reacts in the form of pressure or tendency to escape in proportion to the quantity contained. But the storage is dependent, not as with fluids upon the capacity or size of the *vessel*, but on the "inductive capacity" of the *material of which the vessel is composed*. There is really a strict analogy between the Leyden jar, the secondary battery, and the primary battery: they are all reservoirs, not of a mysterious entity called electricity, but of energy, potential as chemical affinity in the batteries, and as molecular stress in the jar; the plate or pane form of the jar makes this analogy more apparent, because such charged plates can be connected up for different purposes, just as those of batteries are. The bottle form was accidentally used in an experiment as to the action of electricity on water: it is the best for electricity at high potential, because its closed form gives most resistance to discharge. It consists of a glass or ebonite jar, covered inside and out with tinfoil, except at the upper part, where the surface should be varnished; it should have a cover of insulating material, in the centre of which a brass knob forms the conductor, connected to the inner coating by a wire terminating in a soft wire brush or piece of metal chain. Sheets of glass or ebonite coated on both sides may be used mounted in a frame, but will not bear so high a strain as jars. Either form may be combined (like galvanic batteries) for "quantity"

as one, in multiple arc, or for "force" in series. Also, to obtain either condition from the other, they may be charged from a low-power source as one, and then connected for discharge in series, or they may be charged in series, from a powerful source, and discharged as one for quantity. This used to be called "charging in cascade."

84. CONDENSERS.—These are used for receiving charges of a low potential and are of much value in cable telegraphy, and with induction coils; they will not bear very high charges, but are most conveniently described here, because they are in principle, pure Leyden jars. They consist of sheets of some dielectric coated with tinfoil connected alternately to the + and − terminals. Mica is found to be one of the best materials. Paper coated with shellac is sometimes used, but on the whole paraffined paper is best.

The best mode of construction is to cut up the tinfoil into sheets of the size desired, and to make two piles like the leaves of a book, the one representing the outer coating of a jar, containing one sheet more than the other, which represents the inner coating: upon the extreme end of each of these piles place a tinned wire or strip of metal, and by means of a soldering iron run all the edges together so as to make a perfect metallic connection. The foil should be well baked and warmed when about to be used, to drive off all moisture from the surfaces of the metal, and it is well to rub each leaf as it is laid down with a dry warm cloth. Cut sheets of paper large enough to allow a margin of at least an inch round three sides of the foil. The paper should be thin, not highly glazed, and should show no acid reaction by reddening when moistened with a neutral solution of litmus; it should be baked thoroughly dry, placed in a vessel of paraffin kept well over its melting point, and then drained sheet by sheet as smoothly as possible.

FIG. 16.

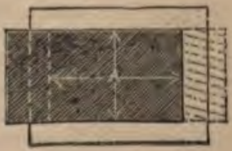


Fig. 16 will explain the process of construction. Place on the table a well-baked piece of wood of the same size or larger than the paper, its face soaked with paraffin and a sheet or two of the paper laid upon it; upon this place the "outer" pile of foil with its soldered end somewhat projecting, and all its leaves turned back except the lowest one, which is to be rubbed smoothly out on the paper; lay over this two sheets of the paper, and on the top of this the other book of foil, so placed that it lies exactly over the first sheet, excepting for the margins at the opposite ends; turn back as with the other all its leaves except the first, and upon this place two sheets of paper; continue this process, laying back upon the paper, sheets of foil from the books alternately, and between each foil two sheets of paper; when the whole are in place, cover with two or three sheets of paper and a board like the first; the whole should then be compressed by clamps or by screws passing through the two boards, and warmed up to the melting point of paraffin, increasing the pressure to drive out all excess. The first board should be provided with a binding screw at each end, and the wire of the corresponding set of foils soldered to it. But the terminals are usually composed of brass blocks on the upper part of a case containing the condenser, fitted with connections for use and so placed that when not in action, the condenser can be short-circuited to secure complete discharge. It is desirable to keep a delicate galvanometer and a battery in circuit through the screws, so that if there be accidental circuit contact during the process, the galvanometer will at once show it. But it must not be forgotten that melted paraffin has considerable conductivity, as also has shellac varnish until perfectly dry.

85. CHARGE AND INDUCTION.—We can produce two effects upon a gold-leaf electrometer or a pair of suspended pith balls. If we rub a piece of ebonite, and approach it to the knob from which the leaves or balls are suspended, they gradually move apart; if contact is made, or if we connect the knob to the conductor of a machine, the leaves remain apart when the contact is broken and the electrometer is left isolated. The leaves are then said to be electrified or in a condition of *charge*. The same condition is produced in any body which has been thus placed in a circuit from an electric source, so as to effect what we may call a *transfer of electricity* to it. The state of affairs produced is such as would arise from the deposit of some agent, and this apparent effect was the origin of the fluid theories of electricity, and of the supposed laws which are still said to govern the distribution of electricity.

If we approach the ebonite to the knob, but not so as to touch, the leaves diverge, but on removal of the ebonite they fall together again, and show no trace of electricity upon them: while diverging they had electricity upon them, but this temporary charge is said to be an *induced charge*.

Further, if the leaves or balls are touched, while thus diverged under the inducing influence, then upon removal of the inductor they continue divergent. This is said to be due to an *induced charge* of the opposite nature to that of the *inductor*.

The divergence of the leaves or balls is said to be due to a repulsive force, due to the self-repulsive nature of electricities of the same name, with which each is charged. These three ideas, *Charge*, *Induction*, *Force*, when clearly worked out, explain the whole of the static actions of electricity, and we must now make a preliminary study of the terms arising from them, leaving the principles to the fuller examination under different heads in succeeding chapters.

86. LAWS OF ATTRACTION AND REPULSION.—Both these effects obey the same laws, and are alike affected by distance of the surfaces and quantity of charge.

Distance.—Taking the same figures as in § 73 where 18° required 144 of torsion force, if the balls be approached to 9° the upper point will move through 567°, and this + 9° is a force of 576. We have thus three distances to compare, 9°, 18°, 36°, which are in the ratios of 1, 2, 4; but the corresponding forces are 36, 144, 576, the ratios of which are 1, 4, 16. Hence we learn that the repulsive force between two bodies similarly electrified varies *inversely as the square of the distance.*

Quantity.—If the instrument be now charged as before and the force measured at a fixed distance, and if the fixed ball be now removed and discharged, when replaced it will again divide the charge, which will be only one-half of what it was before, but it will be found the *force* is only one-quarter of the former force: if the process be repeated the quantity or charge will be reduced to one-quarter and the *force* to one-sixteenth. This proves that at equal distances, the force between two similarly electrified bodies varies *as the product of the quantities of the charges.* When the quantity is equal and opposite, the result is that the attractive force is as the square of the quantity.

Combining the two, the force is $\frac{Q \times Q}{D^2}$. Now $\frac{M \times M}{D^2}$ is the law of gravitation, the attractive force being as the product of the masses in gravitation, and of the quantities in electricity, and in both, inversely as the squares of the distances.

87. QUANTITY.—This apparently simple term is most difficult to define. In currents we have a definite measure for quantity in chemical action: there is nothing like this in static electricity. Static electricity deals only with force and energy: there is no static "*quantity*" existent, only an *attraction*; so that while we speak of static quantity we can only define it in terms of force: it means the force acting within an area or space. As will be seen when the system of units is studied, there are two systems of measurement of so-called "quantity"; upon the electrostatic system, the unit *quantity is that which at one unit of distance repels an equal similar quantity with unit force.* In the

centimetre-gramme-second or C.G.S. system, unit quantity is that which at the distance of 1 centimetre exerts a force of one dyne.

The most satisfactory conception of this is, *a line of force*, which we may materialize as a strained spring of defined strength: but for purposes of calculation and experiment the conception of a fluid called electricity (though erroneous and misleading in many other cases) answers the requirements. That is of course how the fluid hypothesis came to be devised when these phenomena, to which it fits, were all that was known of electricity.

The units just mentioned will be fully explained in the chapter on Measurement. At present the simplest conception of quantity will best serve the purpose of the student, such as the charges taken by a small jar, which is in fact the electrostatic unit, which may be defined also as the quantity contained on an isolated sphere of 1 centimetre radius in air, *under unit Potential*; for the imaginary fluid acts like gases; just as these vary in quantity in a receiver as the pressure varies, so "quantity" or charge varies in the ratio of potential in a fixed receiver or condenser. Electrometers only measure quantity by means of this relation; their action is due directly to the potential, and attractions in the field, or inductive circuit of which they form a portion.

88. DENSITY.—This term represents the "quantity per unit area," that is, the number of lines of force or units of electricity concentrated upon a unit surface. Density is equal at all parts of a sphere at a great distance from surrounding bodies, or surrounded by a concentric sphere: it is equal also at all parts of large plates opposed to each other at a small distance. Where the distance of surfaces is not equal at all parts, the density is greater as the distance between the opposed surfaces is less, that is to say, the density is inversely as the inductive resistance. As a consequence it is greatest at any projecting points or edges: this is due to two causes: (1) So many lines of force can form from any surface as can pass from it to the opposed surfaces: from a sphere this is alike at all parts; but a cone will have its capacity for lines of force increase as its length increases, while at the point it will be a centre for the whole opposing area except that of the cone behind it. (2) The law of inverse squares, owing to which the force or attractions on each part of the surface increase as the square of the reduction of distance due to the projection. It is usual in text-*books, to give* pictures of spheres, ellipses, and so on, with *dotted lines surrounding* them to illustrate the density, or as

some say the depth of the stratum of electricity on the various parts. These are misleading, because they ignore the fundamental fact that the distribution does not depend on the form of the charged body, but upon the position of the equal opposite charge, which is inseparable from it. Some books endeavour to counteract this by saying that the distribution shown is correct only when the charged bodies are at a great distance from all other surfaces. It appears better for the student to look at the general truths involved, that is, to examine the dielectric to which the surfaces are electrodes, and the length of the lines of force, rather than a mere isolated example, because that happened to be what presented itself to the early observers.

In the case of two concentric spheres oppositely charged it is evident the densities must be inversely as the squares of the two radii, because this is the ratio of areas or surfaces of the spheres. Now in the case of a single charged sphere in the middle of a room, we may regard the surrounding walls as a sphere, and if the radius of the ball is 1 inch and that of the walls 6 feet (12-foot room), or 72 inches, it is evident that the density upon any part of the walls will be as $72^2 = 5184$ is to 1. This is the reason that this opposing charge was so long undiscovered and is in ordinary cases inappreciable.

When the density exceeds a degree varying with the nature of the material, the dielectric breaks down and discharge occurs; this maximum density for air is about 20 electro-static units per square centimetre.

89. Force.—This is the expression in all mechanical operations for the capacity to produce acceleration: but in statics a force is measured as a *pressure* or a *pull*. We have such a force in electricity, but it is not what is called "electromotive-force." The force in electricity is expressed by the strain set up in a dielectric, and, by the attractions and repulsions—the motions it can cause in a body under its influence.

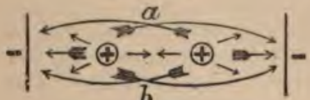
Attraction is the true evidence and action of the force: this is evident from the fact that the normal condition of electricity is with equal opposite + and − facing, and in this state the full force is manifested as attraction, which measures the effort to unite, or to go a step further, the effort of the energy stored as electricity to pass into the form of heat.

Repulsion is an indirect action of attraction: nowhere in nature can there be found a *repulsive force*; there are repellent actions, which are simply transfers of motion, as when one billiard ball strikes another; or else they are actions of a field of force, as in the case of magnetism. As there is always a second surface somewhere, charged with opposite electricity, the apparent repulsion is really an attraction towards that surface; as every charged surface is a boundary of a field of force, in which lines of directive energy exist, so any body free to move in the field moves in the direction of those lines.

Motion of any kind, whether to or from a surface, always means a reduction of the inductive resistance or a transfer of energy along the lines of force.

The action may be traced by Fig. 17. + + are two similarly charged surfaces, while – – are surrounding surfaces; the outer arrows show the direction of the forces from each + to each –, while the two small arrows show the neutralized state of the space enclosed by + and +, *a* and *b*. Inasmuch as attraction varies (§ 86) as the square of the distance, it is evident that the pull in the direction shown by the long arrows must be greatly inferior to that of the short one to the nearest –; hence an *apparent* repulsion between + and +.

FIG. 17.



For purposes of calculation the mathematical system of treating such different actions as + and – forces, is of course convenient. So also, although it is not possible to have unequal quantities of electricity really related to each other, yet it is convenient to treat the different parts of a complicated surface as though each + and – charge were an isolated thing. That is to say, if we have a + charge = 5 and a – charge = 3 there is somewhere another – charge = 2; the true condition is that there exist two distinct inductive circuits 3 + – 3 and 2 + – 2 which are analogous to derived circuits in currents, but we may include the effect of the other circuit by calculating the actions as due to + 5 and – 3, and referring their actions to an artificial datum, or earth.

Force varies as the square of the distance when exerted from a central point, as a necessary consequence of radiant action, because spheres vary in surface area as the squares of their radii. But in flat plates properly guarded, as in the balance electrometer § 74, the attraction is as *the distance.* But though we have thus, *distance* simply in one case, and *square of the distance* in the other, the same law is operating. The flat plates are equivalent to parts of the surface of very large spheres, and the actual distance apart bearing no relation to the length of the imaginary radii, the difference of the squares of the two radii is *practically equal to* the distance apart.

Hence, Force varies as square of Quantity.
" " square of difference of Potential.
" " inversely as square of distance from centre.

90. TENSION.—This term had, in the past, more than one meaning, and has nearly passed out of use, though occasionally employed in the sense of "potential."

According to Fleeming Jenkin, "tension is measured in units of force per unit of area, and is proportional to the square of the density on the element of surface."

The common sense of the word is connected to a pull or attraction; Clerk-Maxwell defines it, "The tension of so many pounds' or grains' weight on the square foot exerted by the air or other dielectric medium, in the direction of the electromotive-force." This means that tension is the "stress" on the dielectric, and in this sense it is occasionally used in these pages.

91. POTENTIAL.—This term is very generally employed in electrical works, because it sounds dignified; but it is very commonly misemployed and still more commonly misunderstood. It is used properly and advantageously in the more abstract investigations of "static electricity," but improperly in dynamic electricity in the place of electromotive-force. The definitions usually given of it are quite unintelligible to the ordinary mind, and only cause confusion of thought. For instance the common definition, *The potential at any point is the work which must be spent upon a unit of positive electricity in bringing it up to that point from an infinite distance,* involves several false assumptions and inconceivable ideas. It is impossible to bring anything from an infinite distance; and it is impossible to bring unit positive electricity anywhere, irrespective of its negative counterpart, which the definition treats as non-existent. In a discussion of the subject in the pages of the *Electrician,* Clerk-Maxwell said, "The theory of electro-statics is greatly simplified by the introduction of this new concept of potential." "As soon as we pass from electro-statics to other departments of electrical science we find that the concept of potential is no longer available, except when used in a restricted sense and under carefully defined conditions." "In other parts of electrical science we have to deal with electromotive-force in cases where 'potential' and consequently 'potential difference' are words without meaning."

Professor Baynes said that potential is the *square root of force.*

Dr. O. Lodge defined the "potential of a point as the potential energy of unit *electricity,* if placed there."

I *should define electric potential* as an imaginary function, or condition, which it is mathematically convenient to attribute to the potential energy stored in a charge, and that, as Professor Baynes says, it is the square root of the electric force existing, and due to the mode in which the potential energy is stored: but this subject will be found discussed in the chapters on Electromotive-force and Current.

92. The ideas embodied in "potential" are not confined to electricity, though the use of the word is very nearly limited to this science. Its principles are most clearly worked out in connection with water in hydraulics, where we have conditions strongly resembling those of electricity, both as to the static stresses, and the laws of current and energy.

Potential is strictly comparable to the pressure exerted by a column of water upon its base, or to the potential energy possessed by a unit weight at the top of the column. That is, it is as head of water in hydraulics.

Potential and electromotive-force are different ways of regarding the same agency and are equal in value: but one refers to static strains, the other to motion produced. Potential relates to the *Inductive* Circuit. Electromotive-force relates to the *Conductive* Circuit. Both are measured in volts, and both are equal at the same point.

93. The term potential is often employed in a very mystifying manner: for instance, it is said that all the parts of a metallic surface are at one potential, because if they were not so, current would flow along it. But this is reasoning in a vicious circle; the potential itself is defined as the power to set up the current. The parts of the surface are at one potential only in the artificial, mathematical, electrical sense; that is, as related to an imaginary zero. But if a surface varies in its distance from its opposed surface, if for instance the two surfaces are inclined to each other, the attractive forces, therefore the potentials, the density will vary all along the surface: every part of it will have its own inductive circuit, with its own proper potential. The different parts of the one surface have no relation to each other in this aspect, any more than if they were cut up into a series of insulated parts. See § 97.

It is also commonly stated that, in this artificial electricity, the potential is the same at the end of a long point, as it is on the sphere to which the point may be connected: this is also a consequence of the definition and *because they are connected*: but the electromotive-force, the tendency to discharge, the relation to the opposed surface, are very different at the sphere and the point.

As this work deals only with the electricity which exists in nature, the term must never be understood in these pages as conveying any of these imaginations, but purely as the static analogue of Dynamic Electromotive-force.

94. DISTRIBUTION OF ELECTRICITY.—Most electrical works occupy many pages in showing that *Static electricity is found and exists only on the surfaces of bodies.* Faraday made many beautiful experiments to show this, and to prove, among other things, that it is found only on *external* surfaces. In fact, this is the sole meaning of the statement as made by the earlier electricians, who experimented with objects placed in a room, and considered only the actions observed on those objects: these theories of charge by a single electricity, were destroyed when it was found that electricity could be placed upon an *internal* surface. But writers still use the old form of words when the meaning is changed. The great importance of clearing away these delusions, brings the subject frequently before us, for clearly realizing the dual nature of electricity, and its action in a field of force lays a sound foundation for the whole structure of the comprehension of electrical action. As the question of surface action will be thoroughly examined, one illustration of the *apparent* confinement to *external* surfaces will suffice. Faraday used a conical bag of stiff muslin, provided with silk cords by which it could be turned inside out, and mounted on a metal ring supported on an insulating stand. If a charged body is introduced into the open mouth and touched to the bag, the electricity passes to the outside, on which all the fibres will rise: no trace of any is to be found in the interior; if now, by means of the strings, the bag is turned inside out, the electricity at once passes to the other and now outer side.

Faraday also showed that inside an insulated chamber built within another room, and strongly charged with electricity, the most delicate instruments contained in and connected to it showed no trace of action. The experiment has been repeated by others, but important as it was at the time, it only proves a detail of a general law. *The static actions of electricity are manifested at surfaces because these are the boundaries of the field of force in which the electric charge exists.* The law and its reason are obvious: Electricity in its static manifestations *must be found only on surfaces* where the polarized circuit passes from one body to another; it is a state of strained rest, unmoving tension, and can only be discovered by transferring that state of tension to another body.

As Mr. Wolcott, of America, aptly shows, a shadow gives us an exact analogue: it presents an appearance of actuality, it is found only on a surface, yet it is merely the manifestation of a state which exists in the whole space between the two related surfaces, that which generates and that which receives the shadow.

95. The two great authorities on electrical distribution and its consequences are Coulomb and Sir William Harris. The first examined the subject by means of the torsion electrometer, and arrived at certain laws. Sir William Harris, on repeating the experiments, found Coulomb's results only approximately correct, and modified these laws accordingly.

Clerk-Maxwell and others have also studied the subject, and give drawings of the distribution under various conditions showing lines of equal potential, &c., but any laws of distribution and accumulation can only be approximate, and the distribution will vary with every variation in surrounding bodies, that is to say, with every alteration in the lines of *least inductive resistance.*

Spheres distribute the charge equally over their surface provided they are at a great distance from the opposing charge: two or more spheres connected, will divide a charge in proportion to their "capacity," which is as their radii, if regarded as isolated bodies.

Ellipses distribute the electricity more towards their ends as do a series of spheres in contact.

The form of the conductor influences the distribution simply by the relative facilities of generating lines of force to the opposed conductors, and the mode of testing the density is by applying a proof plane, which becomes the surface it covers, appropriating the lines of force terminating there, and constituting with them a new field of force of its own.

96. POINTS.—If the conductor of a machine is fitted with a point, no charge can be obtained; if a pointed conductor be held towards it, no charge can be obtained. The lines of force pass from every part of a surface towards every opposing surface carrying opposite charge: in the case of a sphere, these lines are therefore radial and equal at all parts: in the case of an ellipse, they are parallel along its length and radial at its ends: in the case of a cone, they pass in all directions not covered by its base; and as this cone lengthens, they increase in number till a point terminating a long cone may be regarded as the centre of a sphere, concentrating upon it all the possible lines of force. All substances have their limit of endurance, *their breaking strain*: the dielectric strength of air has its limit, and under these circumstances it breaks down and becomes a conductor: *the breaking* strain of air is reached when the density approaches *20 static units per* square centimetre: we may conceive that in

these circumstances the molecules of air become so strongly charged that they fly off towards the surrounding surfaces. If the points are cased in guttapercha or other substances of greater power of endurance, the limit of charge is largely increased. See § 88.

97. SURFACE DENSITY.—If we take two balls of 1- and 2-inch diameter and charge them both at the same time from one source, the 2-inch will have twice the "quantity" of electricity on it that the other has; but if we apply the two balls to an electroscope, they will both give the same indications, or if both are tested by proof plane and balance, both will be found charged alike. It is necessary therefore to see what will be the effect of altering the extent of surface without altering the so-called quantity of electricity. The usual instrument for this purpose is a sheet of tin-foil mounted on a roller, so that its area can be varied, and fitted with or connected to a pith ball or gold-leaf electroscope. If the foil be charged with its full surface exposed, the electroscope will give an indication corresponding to the charge. Now wind up the foil, and as the exposed surface diminishes the action is concentrated on that smaller surface, and the electrometer indicates accordingly; when the surface is reduced to half, the electrometer indicates doubled action: when the surface is reduced to one-fourth, the electrometer indicates fourfold action. But what is really measured by the electrometer in this case is not "quantity," nor even density upon the foil itself; this should be clearly comprehended. From every part of the surface, *the pith balls included*, lines of force extend to the opposing surfaces; therefore we must regard the foil and the balls as *distinct inductive circuits*, the relative resistances of which are proportional to the relative surfaces. When the foil is reduced in surface to one-half, *its inductive resistance is doubled*, or, in other words, its capacity is halved: the relations of the two circuits are altered, the proportional resistance of the electroscope as compared to that of the foil is only half of what it was at first; hence the lines of force are driven from the foil to the electroscope, increasing the pull upon the balls, the true fact being that the electrometer measures *not the quantity on the foil*, but the action of its *own inductive circuit*: it measures the quantity on the foil and its density indirectly, but only because these bear a definite relation to the similar conditions on itself. This is the point every student of electricity should firmly impress on his mind, that *every possible line of force in an inductive circuit has its own conditions*, that each is really a *derived circuit*, as explained at end of § 93, and should be studied on the same principles as

in the case of a number of wires conveying currents from one electric generator.

98. One of Faraday's beautiful experiments illustrates many principles. Let Fig. 18 represent a room containing *s* a source of electricity, such as an electric machine, to the prime conductor of which is attached a ball +, and the rubber or − terminal to earth, which means the walls of the room, from which the radiating lines indicate the field and lines of force set up in the air; *e* is an electrometer which if connected to + diverges strongly; but if to the walls, only a feeble divergence will manifest a − charge.

Fig. 18.

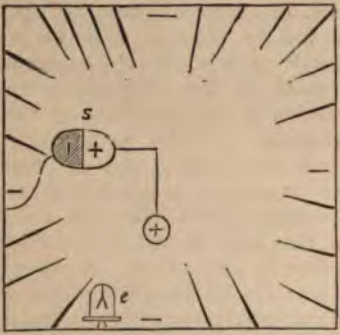
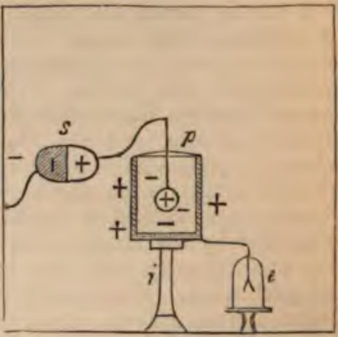


Fig. 19.

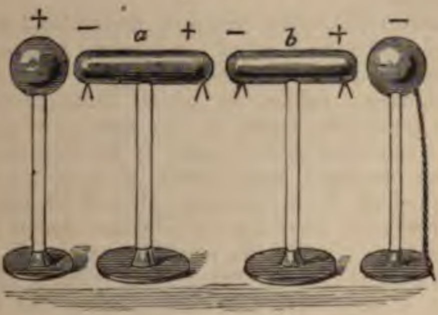


99. Induced Charges.—The experiment is further developed in Fig. 19, where *p* is a metal pail surrounding + and itself insulated by the glass stand *i*. Though the pail is not in contact with + its outer surface will have an equal and similar charge to +, yet if + be now touched to the pail the charge on this will not be increased, nor will *e* indicate any change although + has lost all its charge. The conditions are identical with those of the enclosed sphere § 103 where they are more fully studied.

100. A series of insulated cylinders, as shown Fig. 20, is commonly used to illustrate "Induction," as though it were an action set up by a body possessed of free charge, while it really exhibits the mode in which the chain of polarization is *developed.* + is a charged ball on an insulating stand; if we *imagine it standing* alone, the conditions are those of Fig. 18,

an equal quantity of − electricity existing on the walls; we now bring near it, but not near enough for a spark to pass, the insulated cylinder *a*. This furnishes a new path for the force, and its molecules are polarized, gold leaves or tin-foil suspended at its ends will diverge, and the end nearest + is found to be −, and the other end +. The old explanation was that the free electricity of the ball decomposes the neutral electricity of the cylinder, attracting to its nearest end an equal quantity of the opposite electricity, and repelling the similar to the other end. Add *b*, a similar cylinder, and the same result occurs in it, and in as many as we please. Terminate the series by a ball similar to the first; it, like the cylinders, is polarized; but if by means of a chain or a discharger we connect the ball to "earth" for a moment, we find the ball is then charged with − electricity alone, and to continue the old explanation, its + goes to earth, leaving the free charge opposite to that of the first ball.

Fig. 20.



But the real explanation is this: When *a* is placed near the ball, it presents a more ready path for the force, because its molecules resist less than those of air, hence a twofold action. Its molecules are polarized by the force charged on the air it displaces, but also a disturbance of the previously existing arrangements is produced; instead of the polarization proceeding in all directions equally, *a* presents, by its enlarged surface, a much readier path, and the largest point of the force tends to it, and will result in a spark passing if they approach too closely, while, if this is avoided, a simple redistribution of the lines of force occurs. When *b* is added, a similar result and fresh distribution occurs; and again when the last ball is presented; but when this last is connected to earth, it sets up a circuit of small resistance, confined nearly to the line of balls and cylinders: there always is a partial circuit to the other surfaces, however, so that the – charge on the last ball will never be equal to the + on the first, as the old theory would involve; if touched together while insulated, there always remains a charge on + which is equivalent to the – left on the walls, &c.; so also each successive cylinder will be polarized with diminished force, and will retain on removal a slight positive charge, if the final ball has been connected to earth, because from each of them a fraction of its circuit is completed by the walls instead of through its opposite end to the next cylinder.

101. CONDENSATION.—We can now understand the action of charged surfaces in the form of condensers, such as the Leyden jar, and those used in induction coils, and in those vast condensers, submarine cables, in which these effects of charge produce the great retardation in the passage of signals, which long puzzled practical electricians. If for the charged ball we substitute an insulated metal plate, to each side of which is fixed a pith ball, upon charging it will be seen that these diverge on *both sides*, showing an inductive circuit formed in all directions as from a ball. We now approach to it on one side a similar insulated plate, also fitted with balls or leaves; a very slight effect is produced, the indicators on the nearest sides showing the usual small attractive forces. But if we connect this second plate to "earth" an important effect occurs; the indicators on the outer surfaces collapse, while those on the inner faces show a strong divergence, due not to the supposed repulsive force of similar electricities, but to the attraction of the opposite plate. We see at once that the circuit which was at first formed from the plate to the surrounding surfaces, ceases to exist (or nearly so) and is transferred to the space between the plates, of which the second shows a – charge equal to the + on the first plate. The old theory called this an induced – charge brought up from the earth by the attraction of the + on A, whereas it is simply the actual – counterpart of the + inseparable from it, but constituting with it a field of force wherever it finds the least resistance, that is to say, where there is present at the shortest distances, matter having the most capacity for generating the field, or as the next stage of still lower resistance, matter capable of transmitting electric current. In this state we cannot discharge either of the plates, singly, by any earth connection, we can only slightly diminish the charge; if we touch +, a derived circuit is set up, and a

portion of the positive charge passes to surrounding conductors, and the more distant apart the discs are, the greater this portion will be, because the charge will divide itself in proportion to the resistance of every path open to it. If we next touch −, a similar action occurs, and, step by step, the charge may be removed.

In these conditions, the plates (which exactly represent the two coatings of a Leyden jar) fairly correspond to the two plates of a galvanic cell; connecting one plate to earth, &c., is, the same thing as connecting only one pole of a battery to apparatus. See § 105.

102. BOUND OR DISSIMULATED ELECTRICITY.—These are terms which belong to the old theories: they are meaningless under the new theories, but are still employed in text-books. When, as in § 101, the + charge acts by induction on the cylinder *a*, Fig. 20, it is said to break up the neutral electricity, to attract its − and to repel its + to the further end of the cylinder: this cylinder has then two charges of electricity, of which only the + will leave it when touched to earth. This + is called the *free* charge and the − is said to be *bound* by the attraction of the + ball. The real actions have been explained.

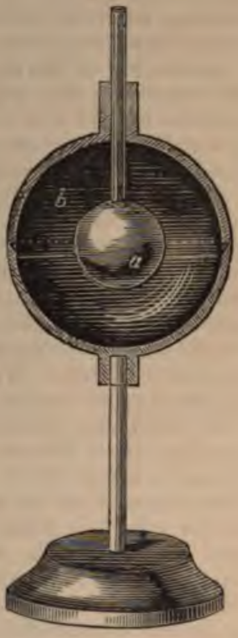
If we take the electroscope, Fig. 8, p. 19, and attach the plate *f*, and place a similar plate upon it, the faces being varnished, we have a condensing electroscope, in which the two correspond to and play the same part as the plates in § 101, while the coating of varnish corresponds to the air between the plates, but with a much greater capacity. If we apply a weak source of electricity to the lower plate, only a very slight action occurs at the leaves; if we touch the upper plate while the source is acting, there will be *accumulation* in the condenser formed by the two plates, because its capacity vastly exceeds that of the highly resisting circuit of the leaves themselves, but as the potential remains the same the leaves show no more action because the two circuits do not disturb each other, each acts as though it were alone, just as in the case of the foil, § 97. If we now remove the upper plate (after disconnecting the source) *the leaves expand*. Why? To quote a common explanation, "the capacity of the condenser diminishes enormously, and the small quantity of electricity is now able to raise the potential of the plates to a higher degree and the gold leaves expand accordingly." The explanation simply obscures the natural facts. The plates have nothing to do with the matter; when the upper plate is removed the condenser ceases to exist, or its capacity is greatly reduced, but there are two distinct circuits through the air to other surfaces; one circuit is from the surface of the plate, the other from that of the leaves: these latter (if there is an earth-plate, as shown, provided by the foil on the glass case) have a circuit of much the lowest resistance, and the action concentrates there just as described in § 101 when the circuit is changed by diversion to the second plate. If in that experiment, the two plates are placed as far apart as possible, they will only receive a certain quantity of electric charge from a source of a given potential, such as a battery: if we approach the plates, they will receive a higher charge, not because the two electricities attract each other more strongly and are therefore able to *bind* more of each other as the books say, but because the resistance of the circuit being diminished, a stronger field of force is generated, just as with the same battery a stronger current is generated when the length of the interposed wire is diminished. If the plates are brought near together, and charged as much as possible, then the placing of a sheet of glass between them would enable more electricity to be taken up, and if ebonite were substituted for the glass this "capacity for electric charge would be still further increased." Thus not only the surfaces taking the apparent charge, but the interposed material in which the charge is really stored, take part in the action: the molecular theory gives a clear explanation of the facts. The charge a given circuit can receive from a given source is in the *inverse ratio of the resistance of that circuit;* or, in other words, *proportional to its inductive capacity.*

103. ENCLOSED SPHERE.—The action of a sphere enclosed in another sphere affords the most complete study of the principles of the inductive circuits, and it is so completely enshrouded in mystery in most of the text-books that it is desirable to examine it, although in so doing we are really going over the ground again, as it involves the principles of all the subjects discussed §§ 99–102. Fig. 21, *a* is a ball of metal, mounted on a glass tube cemented into a neck on *b*, which is a hollow sphere divided in two at its horizontal diameter, so that the upper half may be lifted by the glass tube; the lower half is mounted on an insulating stand. If we now connect *b* to the prime conductor in the usual manner, it will receive a charge, and on lifting the upper half no electricity will be found on the inside of *b*, or on the ball *a*. Even if we insert a wire in the tube and connect *a* and *b*, *a* will receive no charge; but if the wire be left in *a* during removal, then charge will be found on it by transfer from *b*. This is one of the old experiments showing that charge resides only on *external* surfaces. But if we drop a wire through the tube into *a*, and charge it, connecting *b* to earth, that is, to *the rubber of the machine*, then we shall find + electricty on *a*,

and – on the *inside* of *b*, while the *outside will show no signs of electricity*. If the rubber is as usual connected to earth, and also direct to *a*, while *b* is charged +, both inside and outside will be found charged *alike*, and the inner charge will be equal to the – charge found on *a*, and greater than the outer charge, this being due to the smaller space of air between the *inside* of *b* and *a*, as compared with that between the *outside* of *b* and surrounding bodies; we have in fact here two *inductive circuits* as in the other cases.

Again, if we charge *a* as before, and then by a discharger connect the wire leading to it with the outside of *b*, on removing the upper part no trace of electricity will be found remaining on *a*, if the rubber is connected to "earth." Further, if we charge *a* from the conductor, the rubber being to earth and *b* not connected to the machine at all, we shall find that its inside is in a – condition and its outside +, and this outer charge will be equal in quantity to that on *a*, and yet although the outside and inside are in intimate metallic contact, these two electricities will not re-unite as long as the charge is maintained upon *a*; here, *b* is under the same conditions as the pail, § 99. This is a simple matter which the text-books render mysterious by the introduction of "potential." They say that no current passes from the outside of *b* to the inside, because although differently charged + and – *they are at the same potential*, the evidence that they are at this same potential being the fact that the current does not pass; this reasoning in a circle is unnecessary, and the use of the idea of potential here is misleading. If it were said that there was no *difference of potential* between them, it would be merely a roundabout way of saying that the opposite charges on the two sides belong to two entirely distinct circuits having no relation of potential between them at all.

FIG. 21.



When the circuit is internal, by charging from the two poles of an insulated source, there is no external evidence of the presence of *electric charge*. There is no reason why there should be, but an elaborate explanation of the natural necessary fact is provided in the mathematical theory. As the action of charge upon a sphere is the same as if it were concentrated at the centre, § 107 (*a*), it is argued that the + charge on *a*, and the equal – charge on the inside of *b*, having equal opposite actions from the common centre, neutralize each other's external actions—actions which have no existence at all.

104. LEYDEN JAR.—It is obvious that the conditions of the Leyden jar are identical with those of the two spheres, so that we may trace out some important parts of Electrical Theory by aid of these familiar instruments.

According to the mathematical theory of electricity, current, and discharge, &c., are due to *difference of potential*, the actual position of the two points on what we may call the "scale of potential" having no influence. When the word "potential" is used by itself it expresses the difference of potential from an assumed zero, usually the earth. Such a scale of potential is analogous to a vertical column of water in which different pressures may be obtained at different heights. The same effect will occur between two points in an electric circuit, whether those points are at + 15 and + 5 potential as regards zero, and though both of them have free + charges, as would occur between two points at + 5 and – 5, with equal free + and – charges. The facts are, of course, true, and for some of the purposes of calculation, the theory has its advantages. But the theory is not true as a fact of nature. The water analogy itself disproves it; the column of water below the point at which current passes is inert, *it is not in the circuit.* But there is no such thing as a – pressure in the column of water; the real pressure is always +, always in one direction, and is related to the centre of the earth. It is the same in electricity; there is no actual + and – (as in the old fluid theories), these merely represent the relations of opposed sides in the *individual circuits alone*: the same point of space may be + to one circuit and – to another circuit, but these two circuits are wholly independent. The scale of potential is a purely arbitrary conception; what really exists is lines of force, with a directive influence upon energy.

We may take the two supposed jars (15 + 5 +) and (5 + 5 –) and join the two external coatings together, no matter whether they be both + or one + and the other –, and we may then connect both to the supposed zero of potential, the earth, without producing any effect upon the charges.

To meet this fact the other artificial doctrine of *bound electricity was invented*, and this is dealt with § 102. But the jars in this case are exactly analogous to two distinct galvanic cells, which may be combined and connected in exactly the same manner without producing current, as long as the other poles (corresponding to the inner coatings of the jars) are not connected. Under these circumstances we can insulate the jars, either connected or separate, and we can give the external coatings a *free charge.* But what is this but adding a third inductive circuit? We can charge the external coatings + or −, but in so doing we simply make the outside surfaces the one coating to the air of the room to which the other coating is the surrounding surface. We can even put opposite free charges on the two jars in the same manner, and we can make these charges either the same or the opposite of the charges which their inner surfaces bear.

105. When we put the Leyden jar in the form of flat plates we can see that there is a strict analogy between it and batteries, either primary or secondary: they are all reservoirs, not of a mysterious entity—electricity, but of *energy*, in such conditions that its change from potential to kinetic occurs by setting up such molecular changes as constitute electric phenomena. The plates are electrodes to a dielectric in the jar, to electrolytes in the batteries. In the jar the energy is stored in the form of some molecular stress produced in charging; so in the secondary battery chemical stresses or affinities are generated, by an external source (as in the jar), while in the primary battery those same stresses exist in the materials employed. This analogy shows how unnecessary are all the elaborate theories of potential employed to explain the action of the jar. As to residual charge, see § 108 (*i*).

The annexed tabular arrangement, p. 66, illustrates the relations very forcibly.

107. CAPACITY.—It is usual to define capacity for charge as relative to surface, but this disguises the now known fact that dimensions of a surface, or say a sphere, affects the capacity only because it forms a connection to the space and the medium occupying it; therefore the expression is often qualified by the statement, "provided it is at a considerable distance from surrounding surfaces." Readers who have comprehended preceding explanations will understand that a sphere has no capacity at all, *considered by itself*, and that any statements referring to the capacities of single surfaces are merely artificial processes of calculation, not expressions of natural facts.

Capacity is measured by the electric quantity necessary to raise the charge to unit potential.

(*a*) *Spheres.* A sphere of one centimetre radius is taken as the

Static	ELECTRICITY	*Dynamic*
Energy ***potential:*** **stored in a field of force as stress in a dielectric.**	**means**	**Energy** ***kinetic:*** **acting in a conducting path, along molecular chains.**
Inductive	CAPACITY	*Conductive*
Area of dielectric.	varies as	Area of conductor.
Spec. ind. capacity of dielectric.		Specific conductivity of material.
Thickness.	inversely as	Length.
Units of Charge stored under unit Potential.	is measured by	Units of Current transmitted under unit EMF.
The Potential in Volts required for unit Charge.	or by	The EMF in Volts required for unit current.
Inductive	RESISTANCE	*Conductive*
Reciprocal of inductive capacity	is the	Reciprocal of conducting capacity.
CHARGE	ELECTRIC	CURRENT
Potential, in Volts.	is as	Electromotive force, in Volts.
Resistance.	inversely as	Resistance.
Lines of force under stress.	is related to and dependent on	Lines of equivalent molecules forming chains.
Inversely as the several resistances.	divides among several circuits	Inversely as the several resistances.
	ENERGY, OR WORK	
Square of charge in unit or equal resistance.	is as	Square of current in unit or equal resistance.

FORMULÆ.

Charge	$\frac{E}{R} = Q$	Current	$\frac{\mathrm{E}}{\mathrm{R}} = \mathrm{C}$
Potential	$Q \times R = E$	Electromotive force	$\mathrm{C} \times \mathrm{R} = \mathrm{E}$
Resistance	$\frac{E}{Q} = R$	Resistance	$\frac{\mathrm{E}}{\mathrm{C}} = \mathrm{R}$

unit of capacity in the centimetre-gramme-second system of measurement.

Capacity of spheres varies as their radii.

A charge on a sphere acts externally as though it were located *at the centre of* the sphere. See § 103.

(b) Concentric spheres have a capacity dependent on the rela-

tive radii r, measured by the formula $\frac{r \times r^1}{r^1 - r}$, in which r^1 is the outer sphere. The rationale of this formula is that it represents the capacity due to the product of the two radii, and inversely to the thickness of the dielectric, which is the difference of the radii. Now, if the inner sphere is a small ball, while the outer is represented by distant surfaces, a moderate increase of the radius of the ball does not much affect the thickness, or distance, so that the capacity varies nearly as the radius of the ball as in case (*a*); if the two spheres are very close, their radii only affect the formulæ by the corresponding surfaces, and the principal element is the thickness of the dielectric, and the result is the same as in (*c*) and (*e*).

The actual capacity in any given case is ascertained by multiplying the result by the specific inductive capacity of the dielectric enclosed between the two spheres.

(*c*) *Concentric cylinders*, such as Leyden jars, or submarine cables, have a capacity dependent upon their length and their diameters; that is to say, really upon the efficient thickness of the enclosed dielectric, and also upon the sp. ind. cap. The formula is $K = \frac{k\,l}{\log.\ \frac{D}{d}}$, in which K is the inductive capacity; k, the sp. ind. cap. of the dielectric; l, the length; D, the outer diameter; and d, the inner. The formula furnishes the current-giving power of cylindrical batteries, because the logarithmic ratio of the cylinders expresses the internal resistance.

(*d*) For *pairs of plates* of any form the formula is $K = k\,\frac{S}{4\pi t}$. It will be instructive to comprehend the part played here by 4π. (π being used in all formulæ for the circumference ratio 3·14159.) In the case of a sphere the constant ratio of the force to the surface density is 4π, and this is connected to the relation of the surface of a sphere to its radius, which is $4\pi \times r^2$; that is, four times the circumference ratio, multiplied by the square of the radius. Now flat plates may be considered as parts of the surfaces of very large spheres, and the formula is derived from this artificial representation, combined with the treating the two charges as acting from the centre of the imaginary sphere. § 103.

(*e*) The formula can, therefore, be simplified by passing from abstract mathematical conceptions to practical conditions, by using unit dimensions and values. If we take one square foot as unit *of surface, and one mil* as unit of thickness, using the sp. ind. cap. of plates of those dimensions, the formula becomes $K = k \frac{S}{t}$, and furnishes the capacity in microfarads; k in this case is the unit value in the table, p. 71. In this case t, the thickness of the dielectric, represents the infinitesimal difference between the two imaginary radii, and therefore the charge is inversely as the thickness, although the forces to which it is attributed vary as the squares of the distances, *reckoned from this ideal centre.*

108. DIELECTRICS.—All substances possess two properties in relation to electricity; all conduct electricity, but with very different facility; all offer a degree of resistance to transmission, and undergo a certain molecular stress: resistance and this susceptibility to stress are not identical, nor even proportionate, yet they have some relation to each other; substances which undergo *stress* and retain the strained condition when the generating force is withdrawn are called *dielectrics*, and the faculty of receiving this stress is called *inductive capacity.*

(*a*) *Inductive capacity*, or electro-static capacity, is measured in "microfarads," and *specific inductive capacity* is the degree of this property possessed by specified or unit dimensions of each particular substance. Inductive capacity varies with temperature, and is generally reduced by heating. It is connected also with the relation of substances to light, for the *specific inductive capacity* of substances is as the square of their *refractive index.*

(*b*) *Resistance of dielectrics* follows the same laws as in conductors; it varies as the thickness and inversely as the area; each substance has its own specific resistance, but in dielectrics it varies inversely as temperature; it is measured in megohms (million of ohms) on account of its magnitude, as compared with that of conductors.

Guttapercha is usually measured at 75° Fahr. as unity, and its specific resistance may become (according to Willoughby Smith) 23·6 at 32°, and be lowered to ·2233 at 100°; but other values are also given, and no doubt much depends upon its purity. The resistance of 1 mil-foot is 1066 megohms.

Indiarubber varies in the same manner, but to only about one-tenth the amount; and the resistance of both increases with pressure. Its resistance for 1 mil-foot is 20,770 megohms.

(*c*) The product of the resistance in megohms, and the capacity in microfarads, of any dielectric, is a constant value at the same temperature, irrespective of dimensions or form.

(d) Dielectrics have each a specific *breaking strain*, or power of *endurance, § 96;* when the "stress" exceeds this, the dielectric

breaks down, and discharge occurs. Even thick glass may be pierced when a powerful charge is concentrated upon a small area by means of pointed conductors; such breaks assume a zigzag line, following the points which offer least resistance, or which have least capacity for stress, and the discharge may break off into several lines, as lightning does.

(*e*) The act of charge alters the dimensions of the dielectric. If a glass tube is filled with water, and a spark led into it by conductors, the water acts momentarily as a dielectric, and the act of discharge shatters the glass to pieces. The expansions and contractions which occur in a condenser are such as to enable audible sounds to be produced as in a telephone. When a transparent dielectric receives a charge it is found that the arrangement of its molecules is altered, so that it acts differently with polarized light, just as is the case when the magnetic field is formed in a transparent substance, and the degree of change produced is proportional to the square of the electric force.

The field of force thus formed is beautifully shown by some experiments recorded in a paper by Messrs. Rücker & Boys, vol. xvii. p. 310, of the Society of Telegraph-Engineers and Electricians. Two cylinders are so arranged in a glass trough, containing a liquid dielectric, that a ray of polarized light can traverse the space between them. Immediately on charging, this space becomes double-refracting, as glass does when under unequal stresses, and the beautiful colours and forms of polarized light are produced.

(*f*) When a current passes into a dielectric, there is first a sudden rush, and then a slow flow, due to two causes.

1. *Leakage*, which is a true current, due to the actual conducting power of the substance, or to any accidental defects, such as cracks in the guttapercha covering a wire.

2. *Soakage*. The dielectric appears to absorb electricity, as though the stress were at first produced in only the nearest and most yielding portions, and then it appears to be gradually developed throughout the mass. Hence, the inductive capacity of any dielectric will be found to be different, if it is taken for a merely momentary charge, the value of the first rush, or after a prolonged electrification. For most purposes, it is the first of these which is of most importance.

(*g*) When a condenser is discharged, a corresponding current is produced; first a rush, then a slow, continuous current, which is the "soakage" coming out. But when a condenser is discharged suddenly, as through a small resistance, the current *oscillates* through a *series of reversals*, diminishing in geometric *progression*. *The cause is probably* the inability of the conductor to at once accommodate itself to the current, that is to what is called its self-induction. A paper by Dr. Fleming in the *Electrician*, xxi. 6, shows the conditions set up. In a high resistance the effect is a current rapidly fading out.

(*h*) It is possible even to send in successive reversed charges, which will follow each other into the mass of the dielectric, and will return as currents of alternate direction. This, also, occurs in long cables, into which successive + and − impulses may follow each other, and appear as signals at the distant end.

(*i*) *Residual charge* is a result of this action. On discharging a jar or condenser, the principal portion of the charge—that due to the first rush in charging—is instantaneously given up; that due to the small current remains in the mass of the substance, and after a time a fresh discharge can be obtained, or several successive ones, each fainter than the preceding one. This residual charge affords evidence of the state of stress existing in the substance: if it is allowed to escape as a very small current through large resistance and a reflecting galvanometer, the spot of light returns slowly towards zero as the charge is given up: but if the Leyden jar be tapped, it flashes across the scale, owing to the sudden discharge. This action is exactly what occurs with a strained bar or spring.

(*k*) For condensers, the most useful dielectric is one of high resistance and high capacity. In telegraph cables, high resistance and low capacity are desirable, because the stored charges effected at each change of current are the cause of "retardation," and limit the working power or rate of signalling.

For the properties of particular dielectrics see also § 111.

109. RETARDATION.—When a conductor and a dielectric constitute derived circuits to each other, the conductor cannot receive the full current due to the EMF employed until the condenser is charged, but the current is a slowly growing one, due at each point of time to the potential the charge has reached in the condenser; therefore it cannot at once influence distant instruments. This is a branch of the subject of "self and mutual induction" which will be discussed in the chapter on Current.

110. SPECIFIC INDUCTIVE CAPACITY.—This is the relative capacity of each substance compared to that of air in the same dimensions, dry air being taken for the standard, as water is taken for the standard of specific gravity. Faraday took up the subject in his practical way, using a condenser composed of one sphere enclosed in another, and with a tube-stem provided with a stop-cock by which the dielectric could be exchanged. The

instrument is identical in principle with Fig. 21, p. 63. He employed two such pairs of spheres of the same size, one containing air and the other the dielectric to be compared, and charging both together from the same source, he measured the "quantity" absorbed by each, which, of course, gives the relative capacity. Other experimenters have used flat plates of measured distance, and availed themselves of the delicate modern electrometers; but the real values are even yet very uncertain. Specific inductive capacity is frequently expressed as that of a centimetre cube, but for practical comprehension, the most convenient form is thin plates as given in Table I., in which I have collected the most reliable and useful particulars. The value *k* can be calculated for any substance by multiplying that of air 0·0323 by the sp. ind. cap. of the substance.

TABLE I.—SPECIFIC INDUCTIVE CAPACITIES.

Dielectric.	Faraday.	*k*. Capacity of plate, 1 ft. square, 1 mil (·001 in.) thick.	Later determinations.	
			Boltzmann.	Gordon.
		Microfarads.		
Dry air	1·0	0·0323	—	—
Resin	1·77	0·0572	2·55	—
Pitch	1·80	0·0581	—	—
Beeswax	1·86	0·0601	—	—
Glass	1·90	0·0614	—	—
Sulphur	1·93	0·0623	3·84	2·58
Shellac	1·95	0·0630	—	2·74
Caoutchouc	2·8	0·0904	—	2·220
Guttapercha	4·2	0·1357	—	2·462
Mica	5·0	0·1620	—	—
Paraffin	—	—	2·32	1·994
Ebonite	—	—	3·15	2·284
Glass: flint	—	—	—	3·054
,, crown	—	—	—	3·243
			Silow.	
Bisulphide of carbon	—	—	—	1·81
Oil of turpentine	—	—	2·153	—
Petroleum	—	—	2·054	—

Dr. Hopkinson, in later experiments, finds an error in Gordon's results, and gives, extra-dense flint-glass 9·5, paraffin wax 2·31, benzol 2·38, bisulphide of carbon 2·67, and commercial oils 3·10, but castor-oil 4·84, *so that it is* evident that much has yet *to be learnt.*

111. Insulating Materials.—The following are some of the substances most useful in constructing apparatus:—

(*a*) *Asbestos* is made into sheets which have many uses, such as covering other materials where there is a risk of sparking; it is also made into yarn and used to insulate wires as a protection in case of heating, while by covering with shellac and other materials, it is rendered impervious to moisture.

(*b*) *Ebonite* has powerful insulating and dielectric properties, but air and especially ozone react on the sulphur, and render its surface conducting, § 29. When warmed it softens, and can be bent into any form, which it retains on cooling. It is about the strongest of all electric exciters. It has been found to transmit some of the rays of light and heat, and has been utilized in some of the remarkable experiments in radiophony, which will be described further on.

(*c*) *Celluloid* is coming into use for constructing battery cells, as it is easily cemented together by a solution of itself: it is really a coarse sort of collodion or gun-cotton made of cotton waste, but has camphor and other materials mixed with it: it should be remembered that it is very inflammable.

(*d*) *Glass* varies greatly in its properties, see § 29. Crystal, containing much lead, is a bad insulator, and all kinds conduct when heated. For most electrical uses the German glass is superior to English, see § 57.

(*e*) *Guttapercha* is used in very thin sheet for condensers and in coils, but paraffined paper replaces it: its porosity and absorption of water are great defects for general uses. As an insulator for wire it fails when exposed to air, because it oxidizes and becomes brittle; but when it is entirely under water it improves and appears practically indestructible.

(*f*) *Ozokerit* is a mineral substance, which by distillation yields a material closely resembling paraffin, and a pitchy residue, which is largely used for insulating wires, by saturating the cotton covering. When first used great hopes were entertained as to its value, as its inductive capacity was found to be slightly greater than guttapercha, while its insulation was tenfold: it does not appear to have fulfilled its promises.

(*g*) *Paraffin* is a most valuable substance: recently melted into a block, it makes an excellent insulating stand; but it becomes permeated with minute cracks which allow moisture to penetrate. Its use in saturating wood and paper is described § 46. It is useful in batteries to resist the action of acids. If the stopper and neck of bottles are warmed, and a piece of paraffin allowed to melt upon them and rubbed in, the stoppers will not set fast, and they make the bottle perfectly tight; also the labels may be protected by warming over a Bunsen burner, or spirit lamp, sufficiently to melt and absorb paraffin. When solid, this is one of the best insulators, but its resistance lowers with warmth, and very much so when melted. If two silk-covered wires are wound side by side on a reel, one end connected to a battery, and the other to a delicate galvanometer also connected to the battery, the other two ends being kept apart, current will be found to pass through the silk; if the reel is now baked carefully, much less current will pass as the silk is dry: if the reel is now soaked with melted paraffin, a considerable current will pass, diminishing as the reel cools, and ultimately becoming inappreciable.

Paraffin forms a sulphur compound by displacement of hydrogen; this is a convenient mode of obtaining small quantities of sulphuretted hydrogen which is given off when paraffin and sulphur are melted together in a test-tube. The residue is a hard red substance which would probably prove useful for electrical purposes.

(*h*) *Shellac* is chiefly used as a varnish dissolved in spirit or mixed with resin and beeswax as a cement for coating vessels or uniting glass and metal. It is a conductor as long as it remains liquid.

(*i*) *Slate* is much used as a basis for commutators and other electric light apparatus, where there is a risk of sparking; but it is liable to contain moisture, and is improved by slow warming and then being kept for some time in melted paraffin to fill up the pores.

(*k*) *Vulcanized Fibre.*—This serves as an advantageous substitute for ebonite for many purposes, such as stands, tubes, and washers; it is much stronger, and does not soften with heat, though it does with moisture. It is composed of cellulose dissolved in zinc chloride, and then treated with sulphur. It works well, and is very useful for washers, as oil does not injure it.

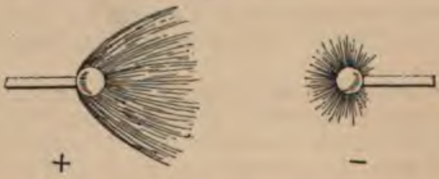
(*l*) *Wood*, as it contains moisture, varies much in its insulating power; it is found to conduct most in the direction of its fibres. The mode of preparing it with paraffin, which makes it an excellent insulator and resister of moisture, is described § 46.

112. DISCHARGE.—So-called static electricity, which means electricity of great tension operating across highly resisting media, develops a current of very short duration analogous to the bursting of a dam in the case of water. The various forms of lightning are natural instances of this disruptive discharge. The action may be considered as due to the independent action

of the single pole, and this was necessarily the earliest opinion, and the basis of the mathematical treatment: this doctrine would involve *unipolar discharge*, § 121. On the other hand we may consider discharge as analogous to electric currents, and due to the combined action of the two poles. But there is certainly a difference in the action of the two poles or electricities: if a discharge be passed through a card by pasting upon its two sides pointed pieces of tinfoil with their points not quite opposite, there will be a burr produced on both sides, indicating that the force is not a penetrating but a pulling one, acting by attraction from each pole; but the hole will be much nearer the – or negative pole.

But the principal evidence of this difference is found in the appearance of the discharge itself; thus the positive pole tends to produce a brush discharge, apparently spreading, while the negative tends to a bright concentrated star form. The effect is shown in Fig. 22.

FIG. 22.



The appearance is modified by circumstances, such as size of the terminals, and their form as balls or points, and the consequent relative densities, and lines of force, but still the *direction* of the polarity alters the effects. A brush will be produced at the rounded end of a wire in both cases, but the negative brush is less defined than the positive. So with the star; if a pointed wire be approached to a large ball, a star forms on the point in both cases, because it concentrates the molecular action; but if the ball be +, the star continues till the point is close to it, only becoming brighter; but if the ball be –, as the point approaches, the star turns to a brush.

113. One feature of electric discharge is important to notice, because it is connected with the theory of electricity; it is always attended with mechanical motion or molecular disturbance. Thus as a general rule, when discharge is occurring there is a stream of air from the discharging points. This is shown in many electrical toys, such as the whirl. In other cases molecular cohesion is destroyed, as in the pierced card and the broken glass of an over-charged Leyden jar. These effects

are similar to those of lightning; thus, if a piece of wood have two wires inserted in it so that the points approach, but are separated by a stratum of wood, a strong charge passed will shatter the wood to pieces.

114. Further study of the electric spark will also show us that a molecular decomposition of the discharging surface occurs. If two pieces of gold leaf be placed on paper with the ends slightly separated and pressed between two non-conducting surfaces, the metal is detached and spread in minute particles over the interval. So in the electric light a stream of molecules of carbon is detached from one pole and carried to the other, the interval being filled with carbon in the state of vapour or gas or absolute molecular division—which is, by-the-bye, the only case in which pure carbon gas is known to be produced.

115. The *colour of the spark* is modified by the nature of the surface giving it, each metal imparting its own colour; and if the spark is examined by the spectroscope we find that it is not electricity passing in a visible form, as is suggested by believers in the existence of electricity as a fluid. The spectrum consists of bright bands varying in their character at different parts of the space across which the spark passes; close to the electrodes these bands are those belonging to the metal of the conductor; these weaken and disappear as the distance increases, and are replaced by those of air or other gas in which the discharge occurs, mingled with others due to the particles of matter floating in the air: the spark consists therefore of the matter which it traverses and renders incandescent.

116. The *length of spark* depends on the difference of potential between the discharging balls: but not according to a definite ascertained law, as in the case of currents; that is, the distance is not in the ratio of the potential. The fullest information we have on this subject is derived from careful experiments by Mr. Warren de la Rue with a battery of 14,400 chloride of silver cells.

With 11,000 cells or a potential of volts 11,330 a spark of 0·62 inch was obtained between points, and below that force it was found that length of spark varied as the square of the potential (which is as the force, § 89). For sparks over ½ an inch long, the potential is about 20,000 volts per inch. But with discs and other forms of electrode this relation does not hold. Upon these data it would require a potential of volts 3,604,000 to produce a lightning flash of 1 mile in length.

117. *Diminished pressure of air* lengthens the spark in the *inverse ratio of pressure:* but Sir W. Thomson and Mr. Gordon

find this holds only down to a pressure of 11 inches of mercury. That is to say that "greater E M F per unit length of air is required to produce a spark at short distances than at long," or according to Mr. Gordon, "at low pressures than at high." Both observers say that "it is difficult even to conjecture an explanation." However I will venture a suggestion. Probably the particles of air are attracted to the two balls and held there in denser strata; certainly the lines of force concentrate upon the balls: the greater the distance apart the less effect this concentration must have on the total resistance, and therefore this may be expected to form a curve dependent upon the ratio the denser portion of the field bears to the total length of the field of force and line of discharge.

At a pressure of about 15 inches the spark discharge tends to pass into a brush which fills the tube: and as the pressure diminishes the phenomena to be observed in "vacuum" tubes are developed, while the colour of the light and especially the spectrum it generates, are those of the gas contained in the tube.

118. *Light affects discharge.*—A paper by Wiedmann and Ebert (see *Electrician*, xx. 324) shows that light modifies the nature of discharge, but principally at the – pole, straggling sparks are brought into single line, without noise, and a telephone attached to the pole gives out a different note. The violet and ultra-violet rays appear to be the most active.

119. DURATION OF SPARK.—In 1834 Wheatstone attempted to measure the time occupied by an electric discharge, and also what he supposed was the velocity of electricity. The principle is susceptible of many useful applications. An object reflected in a mirror is seen in its true proportions, i. e. a point of light will be seen as a point thus . If the mirror is so mounted that it can be rotated rapidly on an axis, this point will be seen in the mirror as a line thus ——. But if the point of light has an existence so momentary as to answer the mathematical definition of a point, no velocity of motion will change its reflection from . to ——, and any such prolongation will be proportionate to the actual duration of the light itself; therefore such duration will be calculable from the angular motion of the mirror while the —— is visible. By this means it was ascertained that the duration of the discharge of a certain Leyden jar was 1–24,000th of a second.

120. VELOCITY OF ELECTRICITY.—The same apparatus was applied to measure the rate at which electricity traversed a conductor; a series of balls were arranged upon a disc in the same plane as the axis of the mirror, so as to form three spaces

of 1-10th inch across which sparks would pass (* * *) after traversing lengths of wire, the sparks 1 and 3 representing the ends of the circuit and the spark 2 its middle. The sparks as drawn out would show the time occupied in transmission, and it was concluded that the velocity was 288,000 miles per second. This deduction was erroneous, and it is known now that if the velocity were measured in this manner in a mile of wire stretched in one length and back again, and then in the same wire wound in one length upon a reel, very different values would be found, and different values, if the reel were of large and small diameters, owing to the different conditions of inductance.

From the various relations of electricity and light it is however nearly certain that the true velocity independent of inductive retardation (§ 109) is the same as that of light, viz. about 185,000 miles per second.

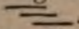
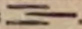
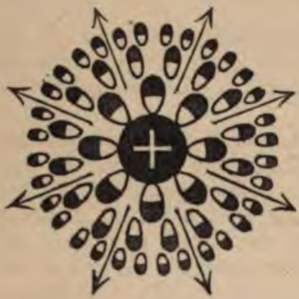
121. Dual Nature of Electricity.—If the electric current were simultaneously developed in the whole circuit, the appearance of the three sparks in the rotating mirror, § 109, would be either ⋮ or ≡ according to the period of their existence. If electric transmission resembled a current of water, and starting from one end of the conductor flowed to the other, passing successively at each opening, the appearance would be . But this is not so; the appearance is . This admits of only one explanation: *the electric current is generated equally at each end of the conductor and flows to the middle.* The working of long telegraph cables shows that momentary electric impulses are of the nature of a wave of influence, such as may be produced by a shake on a rope; the wave travels onwards by virtue of the energy imparted: in cables such successive impulses can be so sent as to follow each other, even though of reverse direction, each travelling independently along the cable and appearing successively at the distant end, resembling the action of dielectrics, § 108.

Fig. 12, p. 33, will explain the nature of the electric impulse. We may consider the middle line of the molecule *a* as being the *locus* or point of origin of the electromotive-force; it would be the surface of contact of a friction apparatus or the face of the zinc plate of a galvanic battery, the point at which energy is transformed into electric force. The polarized molecules at once exert their inductive power *in each direction*, each acting through all the lines open to it and necessarily passing into those of least resistance, where the conditions of neutralization are most readily set up.

122. *Polar Actions.*—All the known facts of electricity

show that it is a dual action. All the theories—the two-fluid, the single fluid + and −, or the molecular theory, which considers the two electricities, or electrifications, as merely the two sides or ends of polarized matter—agree in this. But the mathematical treatment is based upon single and independent actions; this is the meaning of that theory of the earth's action, either in the generation of electricity, in induction, or as return conductor, which regards the earth as a reservoir and sink, from which we can draw or into which we can discharge either + or − electricity separately, and some experimenters have sought to prove the existence of *unipolar actions* such as accord with this treatment, § 125*. In Fig. 23 we have the picture of such supposed actions. The independent pole +, acting as a radiant point, *induces* polar order in all surrounding matter. In such an action it is clear that each circle will be an *equipotential line*, with no tendency to side actions, because the force is radial only, and every particle of matter takes up what force its position presents to it. Every such circle will have equal force acting from it, also radially, and, therefore, the force at each point of each circle will be inversely as the square of its distance from the centre. That is to say, the tension on each molecule in the lines of the field of force thus generated will diminish as the square of its distance.

FIG. 23.



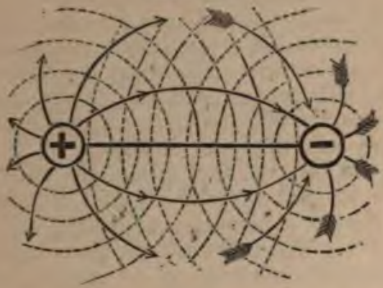
123. Now, we have a perfect physical analogue of this. Let a level plane surface receive a supply of water at its centre, and it will flow outwards in all directions in this exact manner, and its distribution upon and velocity of flow will be identical with the conditions of Fig. 23, in which I have endeavoured to represent the facts by the diminished size and increasing number of molecules as the distance increases.

If we now conceive of some condition which puts this surface out of level, the flow of water will be altered into an elliptic system, narrowing the more as the inclination increases. If we conceive the plane as perfectly balanced on its centre, any cause which induces the water to tend, however slightly, in one direction, will cause the plane to cant over, and direct the flow *more and more in this* direction.

Just such an influence we have in electricity. *The second radial system — is always somewhere ;* it may be conceived as a second system similar to Fig. 23, but with the lines of force and the molecular order reversed.

124. Therefore the circles of these two fields must ultimately meet, and then the lines of force will attract each other with an effect similar to that of tilting the water plane, that is, they convert the two supposed independent radial points into the foci of an ellipse, and the radial lines into the curved lines of a closed field of force. I endeavour to show this action in Fig. 24, but a diagram cannot convey the known fact that the electric force exerts itself in the direction of *most capacity* (better known by the misleading term, *lines of least resistance*), and this, as well as the law of inverse squares, will, therefore, concentrate the action into the space inclosed by the arrows. If, therefore, there be a good conductor in the line, that becomes the shortest path, and is represented by the thick line between + and −. Along this line the constant charge and discharge, or molecular interaction, which we call *current*, is propagated. But the external induction is maintained as a condition of static stress or tension, and constitutes the inductive circuit around the conductor, taking a static charge corresponding to the forces exerted at each point, and the capacity of the medium.

Fig. 24.



125. We may consider this process as a kind of search for the point of union, and as preceding the actual generation of what can be truly called electricity. When we remember that the inductive propagation has a velocity of 185,000 miles per second, § 120, it is easily understood that even though the circuit has to be developed (as in cables) over a path of several thousand miles, the formation of the *beginning* of current, § 109, is instantaneous, *especially as the* inductive circuit really starts from two

adjoining surfaces and can spread, not in full circles, as in Fig. 23, but in gradually advancing arcs similar to the dotted lines of Fig. 10, p. 27, rapidly running along the cable, of which we can consider the molecules *a* as representing the conductor and those of *b* as the sheath.

125*. UNIPOLAR DISCHARGE. Some electricians hold that each electricity acts independent of the other, and that discharge may occur from an isolated pole. One instance of apparent unipolar action is contained in a paper by Messrs. Spottiswoode and Moulton (Phil. Trans., 1879, p. 165). They connected one end of two vacuum tubes (constituting derived circuits) to the − pole of the coil, and the other ends to a ball fixed at some distance from the + pole, so that the current was more interrupted and shorter in duration (as due to a spark) than if coming direct from the wire in a closed circuit. The spark selected one tube rather than the other for its proper path, and in the other tube it only produced a glow extending half-way along it in a reducing cone. Of this tube they said that the discharge in it is, in fact, one which leaves the + pole and enters the tube, but not with sufficient force to pass through it, and so returns on itself. But there is a simple explanation accordant with the universal facts of electricity. The tubes are not quite equal in resistance, or some accidental circumstance in or around them transforms the partial discharge through one tube into a circuit through and along the glass of the tube itself. The authors proved this without seeing it, for they made a tube with an intermediary electrode connected to one of the end terminals and to the + pole, the other end going to − pole. The circuit might be expected, in this case, to confine itself to the latter half of the tube, but actually two cones formed in the other half, representing opposed unipolar discharges. These are evidently a double derived circuit closed on the glass of the tube. This, also, the authors proved without seeing it. Returning to the two-tube experiment, they attached an external conductor to the + pole, and approaching it to the exterior of the tube, just beyond the supposed unipolar cone discharge, they drove it back and stopped it. Obviously, they added an external counter force which, preventing completion of the circuit, prevented also the discharge. The case is precisely like getting a shock from one terminal of a coil, the circuit completing itself through the partially conducting supports. It may be taken as certain that the two poles are indissolubly united and that *each takes equal part in every act of discharge*, and cannot generate electrical discharge until it has found a circuit uniting it to the other.

CHAPTER III.

MAGNETISM.

126. The purpose of this chapter is not to treat of magnetism and its phenomena on their own account, but only to deal with them so far as they are connected with or throw a light upon electricity. Further information will be found also in the chapter on Electro-magnetism.

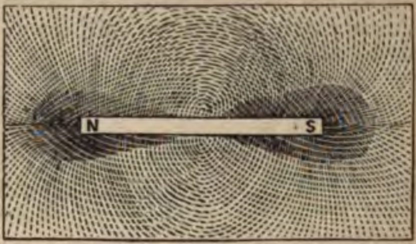
The power of the loadstone, a natural magnetic oxide of iron, Fe_3O_4, to attract iron was discovered in early times, as also that it could impart this property to steel. The first striking property is a directive power by which a bar of magnetized steel places itself in one position, pointing north and south; the next is that when two such bars approach each other, two of the ends attract and two repel each other.

127. It is then found that the active force is concentrated mainly at the two ends of the bar, towards which the holding power on iron is greatest; thus, if a bar magnet be rolled in a mass of iron filings, these will adhere to it in the manner shown in the middle portion of Fig. 25. The intensity at different parts of the bar may be measured by the attraction of a small piece of iron, or by the action on a very small magnetized needle. It is found the pole or point of greatest force is not situated at the extremity of the bar, but at a distance within, varying with the length and form of the magnet, and also with its surroundings. The distribution of magnetic force may be represented by curves similar to those showing static electric distribution. Hence a relation or resemblance between electricity and magnetism was soon perceived, and this led to the hypothesis of two magnetic fluids, the Austral and Boreal, now entirely abandoned, although their brethren, the electric fluids, are still cherished by many philosophers. The resemblance is now leading to the adoption of a similar mathematical theory for the two forces, and to the creation of a parallel set of units of measurement.

128. A remarkable feature in magnetic force is that it apparently acts at a distance without relation to intervening substances, providing these are not themselves magnetic. But

this is only apparent. There is a *specific magnetic capacity* in all substances, just as in electricity, § 110. Iron possesses it in the highest degree, then nickel and cobalt, while other substances possess a very small capacity to retain a magnetic charge, though all transmit magnetic lines of force, unless it is the ether which fulfils this function. Hence a magnet acts as powerfully through glass as through air. If we place a sheet of glass over a bar magnet, and sift iron filings over it, these arrange themselves in obedience to the force, if we lightly tap the glass to aid them in moving. Fig. 25 shows the result, the filings arranging themselves in closed curves which exhibit the lines of force surrounding the magnet, and on which, or, rather, on the tangent to which, at any part, a suspended magnetic needle will place itself. This figure represents therefore a section of a magnetic field; the field itself of course extending round the magnet in all directions.

FIG. 25.

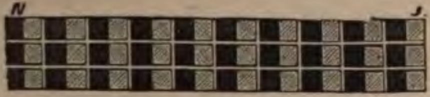


The curves vary according to the position of the several poles in a field: they are formed upon the same principles as those of Figs. 17, 24, and render visible in magnetism the lines and fields of force which can only be perceived by the imagination in electricity.

129. To understand the magnetic condition, we must examine the magnet itself. Thus far we see in it a repetition merely of the electrified cylinders in Fig. 20 with the + and − charges apparently collected upon their separate ends. If, however, one of those cylinders is divided across the middle, we obtain the two parts in the opposite states, one wholly + the other wholly −, and there is thus some ground for the idea that we have really separated two fluids; but this is not the case if we break a magnet across, for we find that two perfect magnets are produced, two fresh and opposite poles being generated out of the previously inert middle, while the forces these possess

are taken from the original terminal poles, the attractive powers of which are reduced. We may repeat this process to an unlimited extent, till we convince ourselves that the perfect magnetic power resides in every minute particle; in fact, that magnetism is a force belonging to and residing in the molecules of which the magnet is composed. This view of the nature of a magnet is well expressed by Fig. 26. This presents the magnet as consisting of a collection of polarized molecules symmetrically arranged, the force of each series exhibited at its two ends, and completing the circuit of polarization or force through the surrounding space as in Fig. 25, where the bar N S represents the dissected magnet of Fig. 26. This conception is strictly correct as to the facts of magnetism itself; but when we come to the theory and to the evident connection of magnetism and electricity, it is apt to generate confusion of ideas, owing to the apparent resemblance between the polarized molecules in both cases.

FIG. 26.



130. To avoid this confusion, and more intelligently to examine the facts and the true relation of the two forces to each other, and to the molecules of matter, it is desirable to define those relations in accordance with the views arrived at as to the relations of electricity to matter. Electricity and magnetism then are the same force, and are two actions of polarized molecules, manifested at right angles to each other, and both developed together. Electricity is the action which occurs *in the line of polarization.* Magnetism is the action which occurs at *right angles to the line of polarization*, and in all directions at right angles to that line. But there are some important distinctions to be noticed. Electricity is essentially a dynamic force, its nature consists in producing motion in, and transmitting energy along, the polarized chains; its static actions are only incidents of this process, dependent on the resistance offered to the completed motion. Magnetism is on the other hand purely static; it consists in the storing up in the polarized molecules of energy derived from dynamic electricity.

Fig. 27 represents a typical molecule, and this figure thoroughly mastered and fixed in the memory will answer every *possible question as to* the relations of magnets and currents, the action of helices, galvanometers, coils, &c. A magnet will always place itself at right angles to such a molecule (forming of course part of a polarized chain), with its north end to the left hand, looking from the molecule itself, so that the arrow or magnet N S is supposed to be on the farther side of the molecule. There is, however, no true directive force in this action, no north and south *sides* to the molecule itself, as there are + and − *ends*, but the directive tendency is the same at right angles to *any radius* of the molecule at right angles to its line of polarization. Thus, if the molecule or current be vertical, and a suspended needle be carried round it, the needle will retain the same relative direction to the molecule, but will make an entire revolution on its own axis, and its extremities will point in turn to every direction, provided the directive action of the earth is neutralized, as by a fixed reversed magnet, for it is the second magnetic field which gives the directive force.

Fig. 27.

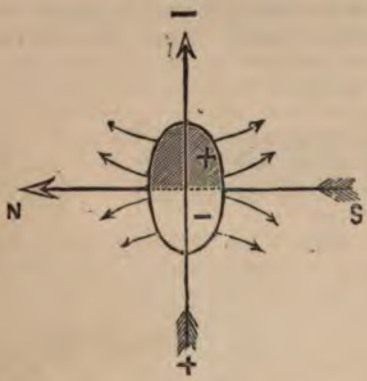
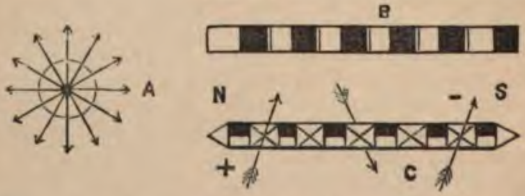


Fig. 28.



131. Fig. 28 will illustrate this. A shows a section of a conductor carrying current, or of the molecule in Fig. 27 with its radial lines, at right angles to which external magnets will place themselves. B represents a filament of a magnet such as is shown in Fig. 26, which conveys a correct idea of the *magnetic* polarities in successive sections, while C exhibits the circular *polarization in these* sections, which is the probable electrical

cause of the magnetic force: the arrows show the directions of a current which would set up this polarization, and generate the N S magnetism shown.

By aid of these figures the student may realize the idea usually employed since Ampère devised it in order to fix on the memory the relations of magnets and currents; for let the reader conceive himself *to be the molecule* Fig. 27, the current of which he forms part, entering at his feet, his head therefore being the + extremity; his right hand will have the magnetic actions of a N pole to any object at which he is looking, and therefore any magnet in front of him will present its N end to his left hand, the magnet itself standing fairly across him in front in whatever direction he may turn.

Another mode of practically using these ideas is to place the right hand upon a wire carrying a current, then if the current passes as from wrist to finger-tips, the thumb will point to N pole of a magnet, so that if the direction either of current or magnetism is known, the direction of the other is evident: if placed *under* the wire, the indications will be equally correct though the direction would be reversed, the palm being in all cases placed against the wire.

132. AMPÈRE'S THEORY.—As before remarked, magnetism was formerly explained by the invention of two fluids; but the theory generally received is that of Ampère. Working from the fact that a circular electrical current constitutes a magnet at right angles to its plane, and that electro-magnets are practically composed of a series of such circular currents in the form of helices, and also from the fact that the force is possessed by the molecules of magnets, he taught that magnetic substances are composed of molecules around which electric currents are always flowing; that in the unmagnetized condition these molecules and currents lie in all directions, and that magnetizing arranges them in parallel order. Fig. 29 exhibits this theory; it shows the magnet built up of the molecules with their currents acting as does an external current shown by the arrows. The bar S shows a longitudinal view of the same magnetic system. The theory explains all the facts of magnetism, but there are fatal objections to it, not generally seen. In the first place, it is based on the idea of electricity being an entity, a something which can circulate round the molecules in a real stream; but though we might assume it to be possible that such circulating currents might be confined to the molecules, it is impossible to conceive how they fail to arrange *themselves symmetrically* always, or why, as in *magnetized iron, they derange* themselves the moment the

inducing magnet is withdrawn. The very nature of electric currents would require a *coercive force* to prevent the magnetic condition being always existent, whereas the reverse is the fact.

FIG. 29.

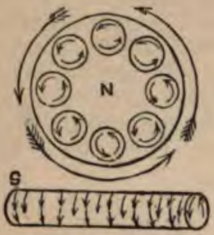
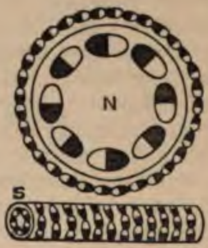


FIG. 30.



133. THE MOLECULAR THEORY.—The theory of electricity set forth in the foregoing pages is equally adapted to magnetism, takes possession of all Ampère's work, and adopts all the facts and all the mathematical problems and proofs based upon them; all of these are unaffected by the substitution for the assumed circulating molecular currents, of the conception of the polarized molecule exerting influence upon all the neighbouring molecules and arranging them in systematic polar order. Fig. 30 shows at a glance both the resemblances and differences of the two theories. N shows the molecules retained as a polarized chain analogous to the conditions of static electricity, and it shows how an electric current generates this state in a bar around which it circulates. The coercive force of the magnet is due to the resistance of the molecules to the change of condition, either to being magnetized or demagnetized in the case of steel, the molecules of which are compound, while iron has little power to resist either. What gives the molecules of iron and steel these properties we do not know. But certain properties are apparently connected with the atomic weights of the elements, which have been classed into groups dependent on numerical relations of these weights. A Russian savant, M. Mendelejeff, has found some difference of properties according to whether the atomic numbers belong to an even or an odd series, as to which information may be found in the second supplement to Watts' 'Dictionary of Chemistry.' It appears that magnetic bodies all belong to the even series, and that diamagnetic bodies belong to the odd series, and that as to these latter the *diamagnetism increases* with the atomic weight.

However, we do know that the act of magnetizing involves the expenditure of energy, which becomes potential and is stored among the molecules and sets up "a force" just as potential energy does in many other cases, as strained springs, raised weights, or chemical decomposition.

134. Those who desire to study magnetism thoroughly, will find some useful suggestions in papers by Dr. Shettle, vol. iii. pp. 10 and 44 of the *Electrician*. His object was to show that magnetism is a spiral force rather than a longitudinal one, but his theory involves, like Ampère's, a continually maintained current of energy. The spiral molecular arrangement, both as to magnetism and electricity, may be almost considered to be established by the experiments of Professor D. E. Hughes, who has proved that the passage of a current through an iron wire produces in it a permanent molecular strain, which is evidently of the nature of a twist or spire, the direction of which depends on that of the current: this twist can actually be removed by a mechanical twist in the opposite direction, or by the application of a magnet pole. He also proved that this molecular twist, in the act of being untwisted mechanically, generates an electric current, just as does the ordinary cessation of magnetism.

135. HUGHES'S THEORY.—This may be stated as—(1) Each molecule of iron is a perfect magnet, as a function of its inherent constitution. (2) That each molecule can be rotated by various forces, mechanical or physical. (3) That the inherent magnetism is a constant quality, like gravity, not to be increased or reduced. (4) In external neutrality the molecules form a closed circuit. (5) In evident magnetism, the molecules have rotated symmetrically, so as to constitute a polar order, with a circuit open at the poles. (6) We have permanent magnetism when molecular rigidity, as in steel, retains them in position; and transient magnetism when they can rotate freely as in soft iron.

136. The essential question as to the various theories is—(1) Is magnetic force an *actual, inherent property of matter*, or of the ether forming part of the molecules of matter (§ 38), which ordinarily form closed circuits: and is magnetizing an opening of this circuit, causing the force to act externally? or (2) Does matter possess, among many other actual and potential faculties, a *capacity* for taking up energy, and assuming a new polar order (§ 15, p. 10) which confers on it the magnetic force? In other words, is magnetization a mere disturbance of an existing equilibrium or polar order? or is it the setting up of a new polar order, accompanied with external relations?

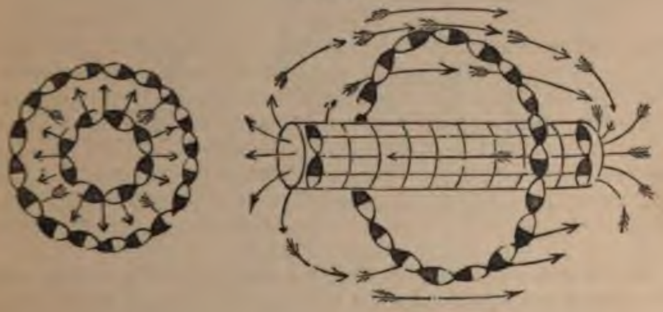
137. A magnet *is usually considered* a mere piece of steel *in which a certain force resides;* it is evident that this is only a

part of the magnet; the external field of force which accompanies it is as essentially a part of it as the steel itself, and the actions of magnetism are all of them merely transfers of the energy of this field and rearrangement of its lines of force. The magnetic force is due to the inductive action of the energized molecules, tending to range all neighbouring molecules in the same order as themselves. They thus set up a magnetic field (which is a resolution of the forces exerted by the various acting molecules) in which all the particles of air and matter range themselves, like the filings in Fig. 25: when a magnetic body enters this field its molecules range themselves in obedience to it, and by their own power set up a field of their own; when the body entering the field is already magnetized permanently, and therefore has its molecules already ranged, or is temporarily magnetized circularly by being the conductor of an electric current, then if movable as a mass, it is turned or attracted or apparently repelled in such manner as to most energetically form part of the original lines of force or magnetic field; but if it cannot move it reacts upon the field and moves the magnet if movable, and a new field is set up which is the resolution of the forces of the two or more magnets within it.

138. MAGNETIC FIELD.—It is of great importance that this conception of a "field of force" should be thoroughly realized and replace the old fallacy of a repulsive *force,* because this supposed force is very apt to mislead in many directions, and it is well to see that throughout all nature we find no trace of a repulsive force, and therefore ought never to apply the idea to any phenomenon merely because it offers an explanation. The action of magnets is the strongest apparent evidence for the existence of such a force, and this makes it the more desirable to show that no such force is necessary to explain the facts. Fig. 31 will convey the idea of a magnetic field, in end view and perspective. It shows the magnetic bar constituted of the annular (or spiral) systems of statically polarized molecules as in Fig. 30. These molecules, exerting magnetic force at right angles, develop the lines of magnetic force as shown in the arrows: the external "field of force" is developed, under the general law of inductive action by circles of polarization in the opposite direction to those of the magnet itself; the magnetic lines of force of these therefore attract, and form closed lines of force with those of the magnetized bar. The external arrows show the position in which another magnet would necessarily place itself, because in so doing the lines of force of the second magnet would place themselves in those of the principal field.

The lines of force of magnetism, like those of electricity, tend to the direction of most capacity, so that whenever a magnetic body enters the field, the lines of force concentrate within it, and the external actions are to that extent suppressed. This is what happens when an armature is applied to a horse-shoe magnet. In the case of a horse-shoe the external field forms itself in the space around the opening, forming an ellipse, with its circles of polarization in the same order as those of the magnet (instead of reversed as in Fig. 31, where the magnetic lines have to return on themselves): on the approach of the armature the lines of force are taken up by the iron, which becomes itself a magnet forming a continuation and completion of the horse-shoe: the energy of the external field develops the force of attraction, and if the armature is sufficiently large and in very good contact, the magnet now ceases to have any external action, because its whole circuit is self-contained. This never occurs completely in the case of an armature, because perfect contact is not to be attained: but if a homogeneous ring of steel were magnetized it would show no external magnetic action: such a ring would manifest opposite free poles of equal strength, at any point at which it might be cut across, and part of its energy would pass into the external circuit which would be then developed.

FIG. 31.



139. ATTRACTION AND REPULSION.—When the magnets approach each other they manifest *attraction* between unlike poles N and S and *repulsion* between like poles N N or S S. When a non-magnetized but magnetic body approaches a magnet it is always *attracted, because* magnetism is *induced* in it as just *described, in true polar order.* If a weak magnet approaches a

strong one, its magnetism may be overpowered by induction either temporarily or permanently, if the fields are opposed.

Attraction is illustrated in Fig. 32 which shows the action of opposite poles approaching: the lines and fields of 1 and 2 enter each other and blend in one: they draw together just as do opposite electric charges, and the two magnets constitute one long one, in which the S N poles at the middle disappear, and their forces are transferred to the external poles, as when two galvanic cells are coupled in series.

Fig. 32.

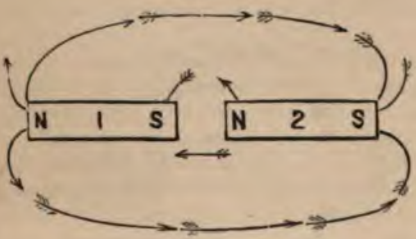
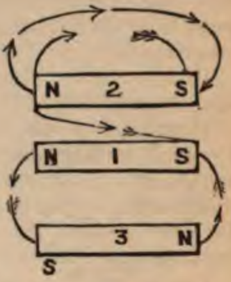


Fig. 33.



Repulsion is explained by Fig. 33, where 1 and 2 are magnets with like poles presented: the lines of 1 S and 2 N coalesce and tend to turn the magnets round, so as to produce the conditions of Fig. 32. If motion is only possible in the vertical line, the magnets will recede from each other because each seeks the molecules of surrounding air to complete its field, and therefore the magnets themselves move in the direction which involves the least interference. Fig. 33 shows also another instance of attraction as between 1 and 3 where both poles act together and each bar acts as the external field of the other.

140. Mechanically Produced Fields.—Fields of force such as are shown in these figures are not merely imaginations: they are capable of being visibly produced by mechanical means, with phenomena strongly resembling those of attraction and repulsion. The curious vortex rings formed of smoke issuing from an opening in a chamber subjected to a sharp blow (and resembling those often produced by cannon) are illustrations of this, for these circling rings possess many of the attributes of solid bodies, moving as a connected whole in space, and even rebounding from each other.

Dr. C. A. Bjerknes of Christiania exhibited at the Paris *Exhibition of 1881* a series of experiments in which the motions *of attraction and repulsion* were very perfectly imitated by means of currents of water. The apparatus consisted of small drums connected to an air-pump which alternately expands and contracts the diaphragms: if two such drums are placed in water so that one of them is movable, and a succession of pulsations imparted to the diaphragms, *attraction* occurs if both pulsate alike, but *repulsion* occurs if the pulsations are alternating.

Mr. A. Stroh in a paper read to the Society of Telegraph Engineers, 27th April, 1882 (vol. xi. p. 192 of the Proceedings of the Society), applied the same principles to vibrations in air. His experiments show just such "fields of force" set up by pulsations in the air as are shown by iron filings in the case of magnetism.

141. LAWS OF MAGNETIC FORCE.—It is generally stated that the attractive force of a magnet varies *inversely as the square of the distance;* but this can only be true of the force exerted by each molecule; no practical law is possible as the effect varies with every change of form, and it is quite possible to make a number of magnets, all of equal power upon an armature in contact, yet all differing in their attraction for their armature at different distances.

Let us conceive two such magnets: A (N—S) with 1 inch between its poles; B (N———S) with 3 inches. The field of A will be the more intense, but it will extend only a small distance from the ends of the magnet: necessarily therefore attraction on the armature will diminish much more slowly, as distance increases, in the wide magnet B, than in the narrow one A. The real law is to be found, not in the distance of the armature, but on the same principles as govern the relations of two derived inductive circuits, §§ 100 and 104. The magnet has in fact two circuits in which to close its lines of force: a reference to Fig. 24, p. 79, will make this clear; if we consider + and − to be the polar extremities of the horse-shoe magnet, the magnetic field is shown by the arrows; it being formed on the same principles as the electric field. If we imagine a bar of iron approaching from above, this, by its greater magnetic capacity, will draw the lines into itself, and two fresh fields will form between its extremities and + and −. It is evident these two fields are a pair in series, dividing the force with the original field in *the ratio of the several capacities*, which may be roughly measured by the relation of the distance between + and −, as against the sum of the distances + armature −, therefore it is a mistake to bring the poles of horse-shoe magnets near together; *they do more work if the opening is wide, because when once in contact* the length of the armature offers small resistance, if it be made of pure soft iron, while this form gives greater range of work.

The force exerted by a magnet holding up a weight is measured in dynes by multiplying the weight in grammes by g the force of gravity at the place, which is about 9·81 in England.

142. Magnetization.—Steel may be magnetized by drawing a bar magnet along its several surfaces, always in one direction; it is still better to arrange a complete system of bars forming an octagon or square, and draw the magnet round and round, always in one direction: in this plan the bars may be all steel, or alternate steel and iron.

If the operator has two bar magnets, an excellent plan is to place them with opposite poles together over the middle of the bar to be magnetized, and then to draw them slowly asunder to the ends, repeating this six or eight times on each face.

Horse-shoes are treated in the same way, closing the poles with a soft iron armature, or a bar magnet properly placed, or two can be arranged facing each other.

The bar magnets may be advantageously replaced by electromagnets which can be given a much higher specific magnetism than steel can retain; this is a great advantage because the magnet can generate no higher intensity than it possesses itself, and therefore the stronger they are the better they magnetize.

143. The Battery Process.—This is the most convenient. It consists in making the steel bar act as the core of an electromagnet for a few seconds. A short coil should be made of stout covered wire, the central opening of which is large enough to allow it to be passed over the bar. It should be arranged at the middle of the bar, and a powerful current sent through it, and passed along the length both ways several times, allowing the ends to half enter the helix, and brought back to the middle before the current is stopped; the action is facilitated by slightly tapping the magnet during the process to produce vibration. The charge is assisted by completing the magnetic circuit externally with soft iron: in this case also the magnetism retained is higher than if the steel is not provided with an armature to complete the magnetic circuit: the reason is that as in compound magnets, part of the lines are apt to return within the mass of the metal.

144. Quality of Steel.—Some say that for large magnets, hardened cast steel is best; for compound horse-shoe magnets *the same annealed at* 500°, or hard shear steel; for needles, cast *steel annealed in boiling* oil. Steel made of the best iron, such

as Swedish, makes the best magnets: but it is very doubtful if *cast* steel is adapted to the purpose. It is now found that about 3 per cent. of tungsten (wolfram) endows steel with high magnetic power; this steel is manufactured at the Allevard works in France, and is now employed for high quality magnets by many makers.

Cast iron will also take permanent magnetism; it should be of a quality containing little carbon, known as white iron, and is improved by the addition of 10 per cent. of steel: it should be tempered or rather hardened at a high temperature.

By care in selection of metal, bar magnets have been produced carrying 20 times their weight, and horse-shoes 40 to 50 times their weight; see § 153.

145. FORM AND ARRANGEMENT.—For compass needles, the best form is flat, tapering from the middle to the points; for bar and horse-shoe magnets the mass of material should be divided into plates not exceeding a quarter-inch in thickness, separately tempered and magnetized, insulated from each other by sheet brass or cardboard, and bound together by screws or bands of brass; in some cases it is well to terminate the whole by pieces of very pure soft iron, shaped as desired, fitted to the end of the bars.

Very powerful magnets are made from very thin steel plates, with the ends gathered into terminal blocks. These, which are called "Jamin's" magnets, are much used for small dynamo machines, fuze exploders, and similar apparatus.

When several bars are thus united, the total force is never equal to the sum of the whole separately, because the similar poles tend to neutralize each other; in some cases the central bars will even be reversed by this action, for which reason they should be the longest. As a rule magnetism is imparted mainly to the exterior portions of the metal, and there is a tendency to complete the circuit through the interior portions of the metal: this is why thick bars are disadvantageous.

146. PRESERVATION OF MAGNETS.—They should be carefully handled, and all jarring actions avoided; when not in use, bars should be placed in the true magnetic direction; or still better, two placed together with their poles reversed, and a small piece of soft iron between them at each end. Horse-shoes should always have the keeper or armature on, and their powers may be increased by hanging them up with a weight attached. Care should be taken never to violently detach the keeper, and when this is removed for use, it should be done by sliding it off across the poles, not by pulling it away.

The power *of a magnet is influenced* by its surroundings, such as neighbouring magnets and currents, and also by temperature: by cooling to 20° C., 36 per cent. of the magnetism is lost; a strong heat demagnetizes steel, and the magnetism even lowers with an ordinary rise of temperature. It is also found that a flash of lightning, even though distant, affects the magnetic force, showing how intimately connected all nature is.

147. *The earth itself is a large magnet*, and this is why the magnetic needle has an apparent directive power, as it places itself on the lines of the earth's magnetic field. Terrestrial magnetism is a subject of vast interest, but it is out of the scope of the present work. Our concern with it is to regard the earth as a huge magnet, and to understand that its actions are the same as those of any other magnet. The poles of the earth's magnetism are not coincident with its axis of revolution, nor are they fixed; hence the *variation of the compass*. It appears as if there were two magnetic axes (that is two N and two S poles) which make a slow revolution around each other, while this compound axis also revolves around the polar axis of the earth in a period of about 320 years. In 1885 the position of the magnetic poles was

North pole.	Latitude 77° 50′;	Longitude 63° 31′ West.
South „	„ 77° 50′;	„ 116° 29′ East.

The *variation*, or declination, besides this general change (about 7′ per year in England and now amounting to 18° 25′ to the westward and diminishing), has annual and daily small variations, due apparently to electric currents generated in the earth by the variation of temperature.

The *intensity or force* is subject to similar variations, caused partly by the change of position of the poles as regards each part of the earth, which at present slowly increases the force in England, and partly by the fluctuations in the causes of magnetism itself, which probably are connected with periodical changes occurring in the sun, and the maximum and minimum periods of sun spots, and also probably with the grouping and relative distances of the planets. Irregular variations accompany displays of aurora, § 97.

The force is considered under two heads.

148. The *dip* or vertical component is the intensity of the attraction with which a perfectly balanced needle is drawn out of the horizontal line with its ends dipping towards the nearest magnetic pole, where it would assume the vertical position. The practical effect is that a magnetized needle requires a counterpoise to balance this force, if it is intended to rest in a horizontal plane.

The *horizontal intensity* is of the most importance, as in galvanometers the value of a deflection produced by a current is proportional to the horizontal intensity of the earth's pull on the needle at the place of observation, which varies from a maximum at the magnetic equator to nothing at the pole: its position of greatest intensity is in latitude 0°, longitude 101°, where it equals dyne ·3733. At Greenwich its value was

	Dynes C.G.S.	Metric M.G.S.
1848	·1716	1·716
1873	·1791	1·791
1875	·1794	1·794
1881	·1805	1·805

An approximate formula for the value at different parts is $\sqrt{1 + 3 \sin^2\lambda}$, where λ is the magnetic latitude or inverse angular distance from the magnetic pole.

Another formula is based upon the assumption that the earth is a uniformly magnetized body, or that it acts as the magnetized field generated by a magnet at its centre; the magnetic moment, § 151, gives $\cdot 33092 \times \sin \lambda$.

149. The *magnetic field*, consisting of lines of force having *direction* and *intensity*, of necessity varies in force at its different parts; the *unit field* is that which exerts unit force on a magnetic pole: but, as in the mutual reaction of two poles, § 150, this magnet itself is a factor in the force, and $F = m \times H$, where m is the moment and H the intensity of the field: distance does not enter into the formula because it is already one of the elements which define the intensity. H, which is always used as the symbol of horizontal intensity, is the field produced by the unit pole (Weber) at the distance of one centimetre, and more generally it is as $M \div D^2$, as the strength of the pole and inversely as the square of the distance. It is proposed to call the unit field intensity a Gauss.

150. The *strength of a pole* resembles the unit quantity of electricity, § 87, and a unit pole means *one which at one centimetre distance repels an equal similar pole with a force of one dyne.* The same formula as is given § 86, $F = m \times m^1 \div D^2$, expresses it, and therefore it is also called the unit of magnetic quantity. Its value is 10^8 C.G.S. units.

The *pole of a magnet is not a fixed point* in it: it is the focus on which the molecular forces combine: therefore this pole or focus will change in position if any cause modifies the field of the magnet, such as the approach of a magnetic substance or another magnet.

151. **Magnetic Moment.**—In mechanics the "moment" of a force is its value under given circumstances, as of the force applied to a lever to move it around its fulcrum. A magnet is a lever, its centre the fulcrum, its poles the point at which the force is applied, and the length of leverage. In such cases the action in opposite directions on the two ends of the lever, exerting an effort, not to move it in any direction bodily, but to turn it on its axis, is called a "couple," and the couple tending to turn any magnet placed at right angles to the pull of the field is $m\,l \times \mathrm{H}$, where $m\,l$ is the *magnetic moment*, depending on m the strength of the pole, and l distance between the poles. Therefore the "moment" of a bar magnet is doubled by another of equal size and intensity, by placing them either end to end, as this gives $2\,l\,m$, or side by side, which gives $2\,m\,l$: in fact the *magnetic moment of any uniformly magnetized substance is proportional to its volume.*

The moments of magnets may be compared by their relative actions as regards another magnet; if we use the earth as this magnet (and do not need the high accuracy which would take into account the varying magnetic intensity of the earth itself) the moment of a bar magnet may be measured by suspending it by a fibre and counting the time of one oscillation or the number of oscillations in a given time, the relative moments are as the square of the number of oscillations, or inversely as the square of the time of one oscillation.

To obtain the moment in absolute measure a very short needle is freely suspended so as to hang in the magnetic meridian over a zero line. The magnet is placed parallel to this line, at right angles to and in the plane of the needle, at such a distance that it produces a deflection of only a few degrees. Let θ be the angle of deflection, d the distance between the centres of the needles, H the horizontal component of the earth's magnetism, § 148, then $m\,l = \mathrm{H}\,d^3 \tan \theta$.

Horse-shoe magnets may be similarly measured if their ends are placed on the line which a bar would occupy, and the distance measured from the central point between them.

Among the examples quoted by Prof. Everett, it is said that Gauss found the magnetic moment of a steel bar magnet weighing 1 lb. (453·6 grammes) to be 10098 C.G.S. units, and that Kolrausch finds that the maximum permanent magnetization retained by steel in very thin rods is such as to represent a capacity of nearly five times this. This gives according to these observers:—

Gauss,	moment per gramme,	22·24.	Intensity,	175	C.G.S.
Kolrausch	„	100·00.	„	785	„

The moment of the earth is ·33092 × R^3 and the radius R being 6·37 × 10^8 centimetres, this is 855 × 10^{23} C.G.S. units.

152. The *intensity of a magnet* is the relation of the force to the mass of matter it is charged on, and varies as the ratio of the magnetic moment to the weight or volume of the magnet; thus, if one bar has a moment equal to that of another of double its weight, it is itself magnetized to twice the intensity. The C.G.S. unit of intensity is that of *a cubic centimetre having unit magnetic moment.* The earth's magnetic intensity is only ·0790 which is about ·000455 of that of Gauss's pound magnet, § 151, and therefore 1 volume of highly magnetized steel has a capacity equal to 2200 volumes of the earth's mass regarded as a uniformly magnetized body.

153. *Magnetic capacity* is the maximum intensity which could be imparted to unit volume of any substance. Prof. Rowland gives the value in C.G.S. units:—

Iron and steel at 12° C. =	1390;	at 220° C.	1360.
Nickel ,,	494;	,,	380.
Cobalt ,,	800?		

Different authorities give values ranging from 400 to 1000 for steel, but full information will be found in the chapter on electro-magnetism.

154. *Saturation* implies that a magnet is charged to the utmost the capacity of its materials will admit. Under the influence of an electric current, the magnetism will at first grow in the ratio of the current, but after a time increase of the current produces a diminishing growth of magnetism, till at length a limit is reached at which no additional current increases the magnetism. Steel reaches this point sooner than soft iron. But when the magnetizing force is suspended, the magnetism is lost to some extent, till an intensity is reached which is tolerably permanent (§ 146). Iron loses the magnetism almost entirely, though a small "residual magnetism" is always retained. The softer and purer the iron the more freely it absorbs and the more completely it gives up the force.

155. *Coercive force* is a name given to this property of resisting and retaining magnetism. If only steel possessed it we might attribute it to some insulating or polar action of its carbon: but as nickel and cobalt both possess it as pure metals, we can only say that we do not know what imparts the quality.

156. *Consequent poles* are similar poles opposed in the bar of metal as (N——SS——N) where we have the apparent anomaly of a magnet with two north poles: such magnets have uses and are largely produced in dynamo machines: but consequent poles

destroy the value of ordinary magnets. If a piece of soft iron is applied to the N end of a bar magnet, it is attracted because polarity is induced in it; it becomes itself a magnet with its S end in contact with the magnet. If, now, a second bar magnet is applied with its S end to the other end of the iron, the action is increased, the iron held with double force; but if the N end of this second bar be applied, the two actions neutralize each other, and the iron, though in contact with two magnets, will have only a slight attraction exerted upon it. In this case the armature has consequent poles formed in it and the opposing fields neutralize each other. The same effect is produced if a N pole approaches the end of a piece of iron hanging from a N pole: the iron may fall off. If a S pole were approached, instead of weakening the attraction of the magnet and tending to draw away the iron, the attractive force would be increased.

157. AURORAS.—These are closely connected with the earth's magnetism, although the exact relation is not known. They are not unfrequently attributed to *electric* discharges, similar to those effected in vacuum tubes, occurring in the upper strata of the air. But the aurora is a general, not a local phenomenon, though it may be more strongly displayed at particular parts. There is ample evidence that auroras are manifested in both north and south polar regions at the same time, and we know that electric currents circulate around the earth as though it were an electro-magnet; the reverse action is, however, possible, and the currents might be due to changes in the magnetism. It seems more probable that the aurora is an illumination of the lines of *magnetic* force: at all events the auroral corona always forms around the position of the magnetic pole, and its lines correspond to those of the magnetic field. There appears also to be some connection between the aurora and *parhelia* or mock suns, which are due to a peculiar arrangement of ice particles in the upper air: this renders it probable that the play of light and colour, and the shifting streamers of the aurora are due to the magnetic lines of force affecting the constantly varying strata of moisture floating in the air.

Prof. Lendstroem of Helsingfors has, it is said, produced auroras by artificial means; he raised a number of points on the summit of two hills, one of them 3600 feet high, in 67° N. lat., connecting these points to earth at the foot of the hill: an aurora was formed rising 300 feet in the air and exhibiting the true auroral spectrum. This result, due to atmospheric electric discharge, is probable, because the aurora strongly resembles some forms of electric discharge: but it would not diminish the probability that the true aurora is a luminous effect of *magnetism* rather than of *electric* discharge.

158. MAGNETIC STORMS.—These are the constant accompaniments of the aurora, but often occur when there is no visible aurora; they have been observed to accompany changes in the sun, and development of sun-spots. They consist in the development of strong but fluctuating currents in the earth, which frequently rise to a force of 200 Daniell cells and occasionally to 2000. The direction is usually from east to west as though the positive current followed the sun. Telegraph lines running east or west become useless, except by connecting two together to form a complete circuit independent of the earth; but lines running north and south are comparatively unaffected.

On 17th and 18th November, 1882, a severe magnetic storm affected the whole earth, and suspended telegraphic communication in great degree. It was accompanied with a brilliant aurora; there were also heavy snowstorms in many places, and at the same period there were several large sun-spots forming in the sun. During this storm the earth's magnetism underwent rapid fluctuations, and the declination varied 1° 18′, and the dip half a degree: simultaneous changes were observed in Europe, America, and Japan.

159. DIAMAGNETISM.—Magnetic effects can be developed in all substances by electrical currents and helices, and Faraday and others have proved that magnetic actions do thus occur, modified by the nature of the substances and their molecular arrangement, which lead to a classification of substances as paramagnetic and diamagnetic.

The first class when interposed between the poles of a magnet, place themselves with their longer axis in the line joining the poles; the latter arrange themselves across that line. There has been a tendency among some philosophers to attribute this to a force distinct from magnetism, but there seems no sufficient reason for it, as the properties of the magnetic field will explain the facts; it would seem more probable that the diamagnetic substances are those in which the faculty of assuming the magnetic condition is feebler than in air, and that therefore the molecules of air form the field more readily than those of say bismuth, and consequently move these latter into the position in which they take up the least portion of the lines of force; thus a tube containing a weak iron solution will be magnetic in air, but suspended in a vessel containing a stronger solution of iron it acts as a diamagnetic substance. Diamagnetism will not be further entered upon in this work.

160. Before leaving the subject of magnetism, it will be well to point out the error of the common conception of magnets as inexhaustible sources of force. It is this misconception which has led so many to waste their time in trying to devise perpetual-

motion machines, of which magnetism was to supply the motive power. It has also given rise to many questions as to how it is that a magnet can impart force to any number of other magnets without itself parting with any force.

Magnets, like springs, can only exert the power which has been put into them: *they have no force of their own.* In the act of magnetizing, whether by magnets or by electricity, a certain amount of energy is charged upon the molecules just as it would if each of the molecules in Fig. 26, p. 83, were a spring which was wound up in the act of magnetizing. Irrespective of theory, this is a proved fact as the heat of solution of magnetized steel is greater than that of the same steel not magnetized. When the magnet exerts any force, *it parts with that force;* it is to that extent exhausted, and the energy it parts with is distributed over the new "field," or in the armature, &c., which has been moved. If the armature is a mass of iron as large and heavy as the magnet can hold, the magnet is exhausted; it will no longer affect external magnets, &c., or but very slightly. Before the magnet can exert any further force, the requisite energy must be restored to its molecules. This is done by removing the armature, which requires an exertion of force equal to that exerted by the magnet in attracting it.

The distinction is simple, but important; the common idea regards the removal of the armature as an exertion of force against the power of the magnet, and in some sense this is so. But the real action is the restoring to the magnet the force which it has given up to its armature, which is effected by the molecules themselves so long as they retain the magnetic condition.

So in the act of magnetizing, it is not the magnet which gives the force, but the energy expended in the act, just as in cutting a piece of iron with a steel chisel it is not a force in the chisel which does the work. The magnet and the chisel have each certain molecular properties which enable external energy to produce the desired effect: in the one case of effecting a molecular arrangement in the steel bar; in the other of destroying the molecular arrangement and cohesion of a piece of iron.

The French and some other foreign writers (and even a few English ones) reverse the polar names. We call the end of a magnet which points to the north pole of the earth, the N pole, but as its magnetic condition is opposite to that of the earth, they say that its proper name is the S pole of the magnet, as its magnetism is *austral* while that of the N pole of the earth is *boreal.* Unless this is understood students may easily misunderstand the meaning.

CHAPTER IV.

GALVANIC BATTERIES.

161. It is difficult to examine the facts of galvanism thoroughly in any progressive order, as advanced knowledge is required to understand the elementary facts: students must, at first, accept the principles and laws necessary to understand the facts, and return to these again after the study of the principles of measurement, &c., based upon the facts.

162. If we place a piece of ordinary sheet zinc in a dilute acid, we find that a tumultuous action takes place, the zinc is dissolved, and hydrogen gas given off. Another effect is produced which is seldom set forth when this fundamental experiment is stated; as the zinc dissolves, the liquid becomes heated. Now this last fact is the one of primary importance; for with all the similar facts in chemistry, it teaches us that whenever an action takes place spontaneously between substances, energy is set free, usually as heat. Let us examine what occurs in this instance, and why it occurs.

The old explanation, even now frequently given, is that the zinc decomposes water, H_2O, gives off the hydrogen, and forms oxide of zinc, ZnO, which is then dissolved by the acid, forming a salt of zinc. The true explanation is far more simple; the acids are substances in which hydrogen forms the base, united with a special acid radical; hydrogen, though a gas, has many chemical analogies with the metals, indeed there is reason to believe that it is a true metal, capable of assuming the solid state in alloy with some other metals, and displaying the ordinary characteristics of metals. At all events, metals are capable of taking its place in compounds; and in the case under consideration, of zinc acting on dilute sulphuric acid, the metal displaces the hydrogen and converts the sulphate of hydrogen, H_2SO_4, into $ZnSO_4$, sulphate of zinc.

163. It is requisite to clearly understand that, besides the material elements, *energy* enters into the constitution of all bodies; all possess a specific quantity of what we know as heat, and according to *the molecular* theory, the atoms of which all *substances are composed* are in a constant state of internal

motion; the amount of that motion governing the physical state, as solid, liquid, or gaseous, and also the chemical relations; even affinity is probably a function of these motions and dependent upon the wave-lengths of the vibrations proper to each element, as shown by the spectroscope; the less the motions the nearer the atoms approach, and the greater the attraction they exert on each other. Hence when what are called *higher affinities* come into action, the internal motions are diminished; but as a consequence, this motion becomes external, active and sensible, instead of internal or latent; and thus it is that every act of chemical combination sets energy free in some form, usually as heat, while every act of chemical decomposition requires the supply of energy to re-establish the internal motions, or latent forces, or, as it is usually expressed, to overcome the chemical affinities. Energy, latent and imperceptible, is called *potential energy;* when external and sensible, as motion, heat, &c., it is called *kinetic energy*—and the two undergo constant transformations of one form into the other.

164. Thus, zinc in dissolving gives off hydrogen and *heat*, while forming the more satisfied compound, sulphate of zinc. If we use a piece of iron it does the same, though more slowly, but if we use copper no such action occurs. If we place in the same sulphuric acid, copper and zinc separate from each other, we see gas pouring off the zinc and not from the copper; but if we permit them to touch, a new phenomenon occurs: the gas appears to issue abundantly from the copper, instead of from the zinc. Still if we examine the liquid we find that no copper is dissolving, while the zinc is dissolving faster than before. Instead of allowing the two metals to touch within the liquid, we connect them by a wire, and we find that this wire is suddenly endowed with extraordinary properties: if it approaches a magnetic needle the earth's directive power is superseded, and the needle no longer points N. and S., but tends to place itself across the wire, and in different directions, according as it is above or below; if the wire be coiled round a piece of iron it endows it with powerful magnetic properties; if the wire be cut in two, and its ends dipped in liquids, it produces chemical changes in many of these; lastly, the wire itself becomes hot. But in proportion as these effects are developed, so does the dissolving zinc generate less and less heat in the liquid. Here we have the explanation of the sources of these external actions; there is no creation of energy; nothing new occurs, except that under the new conditions, the *energy set free* by the combination of the zinc produces the *effect which we call* electricity, instead of that called heat (just

as it was seen occurs with friction, § 23), and is capable of manifesting itself by its chemical, magnetic, or calorific effects, thus furnishing the three natural divisions of the study of dynamic electricity.

165. The conditions under which energy takes this form are those pointed out in § 39, but more plainly evidenced. The fundamental condition is a complete circuit of conducting substances; and where chemical action is the source, part of the circuit must be an electrolyte; that is, a liquid whose molecules will readily assume the condition of polarity, and break up into two distinct parts, giving up energy in the act.

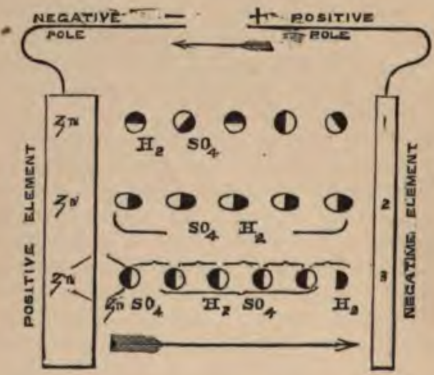
In our experiment the zinc attracts the sulphuric radical, turns the hydrogen half of the molecule away from itself, and by diminishing the internal attractions of this first molecule, disturbs those of others, if there be the chain provided along which the force can act: if not, the hydrogen escapes, and the heat is at once set free. This can be traced by the ordinary chemical symbols. $Zn + H_2SO_4$ first becomes $\overset{\frown}{Zn} + SO_4H_2$, then $ZnSO_4 + H_2$. The atoms of hydrogen are now what is called *nascent*, and would instantly form a free molecule, taking up and rendering latent that portion of energy necessary to convert them into a gas; but before this process is completed they are in a condition of great activity, and eager for combination; being surrounded only by molecules the nature of which is not changed by the hydrogen (that is hydrogen compounds), the decomposition is transmitted along a chain of these: molecule after molecule is decomposed, and the hydrogen is not set free until it reaches a point at which it is powerless to effect a decomposition; thus, in the combination under examination, it reaches the copper plate before it becomes free.

166. If, at this point, there is present a substance which will take up the hydrogen, with less energy than is needed to set it free, another action occurs; such a substance is sulphate of copper, from which the hydrogen displaces the copper, which fixes itself in turn upon the superficial molecules of the metallic plate, to which the polarizing force is transferred, and from it transmitted to the external conductor; these two processes furnish us with a natural division of batteries into: (1) Those in which the hydrogen gas is set free; (2) those in which the hydrogen displaces some other substance; and this latter class consists of two kinds, those in which one liquid fulfils all the requirements, and those in which two liquids are required, kept apart by a porous partition.

167. *We must now explain* some terms as to which there is

apt to be confusion. As the action commences at the surface of contact of zinc and acid, the zinc is called the positive *metal* or element: the order of polarization in the liquid is such that the positive or + ends of the molecules turn *from* the zinc, and the negative ends, which are the acid radicals, turn *towards* it. This corresponds with the terms of static electricity, and shows the wire leading from the zinc plate and called its *pole*, in the same electrical condition as the rubber of a glass electrical machine — or negative. The action passing through the liquid to the copper or other collecting plate polarizes its molecules with their – ends to the liquid, and their + or positive ends towards its wire. Hence we have the zinc, the positive *metal*, *plate*, or *element*, but its wire, the negative or – *pole*; the copper is the negative *plate* or *metal*, but the wire proceeding from it the positive or + pole. Fig. 34 shows this, and explains one cycle of the reactions.

Fig. 34.



Line 1 exhibits the arrangement before action, the molecules indifferent, the shaded part representing the +, metallic, or basic element or half; the white being the – or acid half. In line 2 we see the molecules polarized under the attraction of the zinc; in line 3 this whole chain breaks up, one atom of zinc dissolving, and forming a molecule of zinc sulphate; at the other end of the chain, the two atoms of hydrogen set free satisfy each other's attractions, and form a molecule of hydrogen *gas. Then* the action is repeated, the molecules making a semi-*revolution, and resuming* the position of line 2. It will be seen that this view of the action involves two actions at each stage, first the semi-revolution of the molecules on their axes; and, secondly, the overcoming the chemical attraction within the molecules; this latter also involves two separate actions; the actual disruption, which occurs only as to one molecule of the chain and the temporary disruption and reforming of all the other molecules in each chain. These various actions cause the internal resistance of batteries, while the energy given up during the interchange of zinc for hydrogen in sulphuric acid is the source of the electromotive force.

168. We are thus led to the three fundamental expressions used in Ohm's formulæ, viz. electromotive force, resistance, and current. It is upon a clear understanding of these, in a perfectly definite form, in place of the confusion of the old vague terms "quantity and intensity," that sound and economical working must be based. The full explanation of these terms must be studied in the chapters devoted to each of them; but a slight definition is necessary for present purposes.

169. *Current* is the rate of electric action, or, subject to the explanations of § 87, it may be, and commonly is described as the *quantity* of electricity transmitted in unit time, just as with a current of water. It is measurable by its electric actions, which within certain limits are proportional to the rate of current flow; this enables currents to be practically seen and measured by their action on the magnetic needle in *galvanometers*. But from the theoretical point of view, that is, to enable the principles of action to be clearly understood, the measurement by chemical action is the most important.

The quantity of electricity, or the rate of current, is exactly proportionate to the quantity of zinc dissolved in *one cell*, and to its rate of consumption: and in every cell in a circuit there will be chemical action equivalent to that of the one cell taken as the unit. This is measured in *voltameters* which show either the quantity of a gas set free, or the weight of a metal deposited or dissolved. Thus in a Daniell cell, for every 32·6 grains of zinc consumed 31·75 grains of copper would be deposited, and if the current were passed through a silver solution and a gas voltameter, 108 grains of silver would be deposited and 1 grain of hydrogen produced: so with all the materials, as acids or salts, *equivalent* quantities would have to be provided.

170. Current is symbolised by C and its unit is the AMPERE, but this is an artificial unit related to energy and magnetic effects in a second of time. At present a more natural unit related to chemical action will convey the principles involved much *more clearly*. The atomic and equivalent weights of

substances are purely relative, they may be grains or tons: but if we take for them a fixed value and start with one grain of hydrogen we have the most perfect unit of chemical and electric quantity, as that which effects one equivalent of action. To convert this into "current," time has to be taken into account, and for convenience of calculation I take ten hours. Then we measure electric currents by 1 grain of hydrogen, or equivalent action in ten hours. This unit, from its source I call a "*chemic*," and throughout this chapter the chemic will be what is meant by a unit of current, while the term unit of any substance means the quantity equivalent to this current. The ampere (which corresponds to about gramme 0·0000104, or 5, or about grain ·000161 of hydrogen per second, and therefore is not convenient as an equivalent basis) corresponds to about 5·68 chemics.

171. *Resistance*, symbolised by R, is an expression of the conditions of the circuit, its capacity to transmit current, and the work expended in doing so. It is to be considered in two portions: (1) *internal*, due to size of plates, conducting power of solutions and porous cells; (2) *external*, due to the nature of the material of the conductor, and the work doing. Work is best done when these two are equal. But internal resistance is comparable to engine friction, it is waste: therefore the greater the external resistance compared to the internal the less the expense of working.

The unit of resistance is the ohm, and may be conceived as represented by a wire of pure copper ·01 inch diameter, 10 feet long, and weighing 2 grains per foot.

172. *Electromotive force*, shortly written E M F and symbolised by E in formulæ, measures the generative power in terms of potential, § 92 p. 54, that is of the capacity to generate current, or of the capacity to overcome resistance. It depends entirely upon the "intrinsic energy" set free by each equivalent acting chemically, and charged upon the molecular conducting chain which transmits the action. The unit E M F is called the volt, and is a little less than the force of a Daniell cell, which is volt 1·079.

173. *Ohm's formula* $C = \frac{E}{R}$ represents the relations, and shows that the current is proportional, directly to the E M F and inversely to the resistance, so that either two being known, the other can be calculated by the system of related units: thus the E M F in volts divided by the R in ohms gives the current in *amperes*. If, in a given circuit we double the E M F, the *current will be doubled*: if we double the resistance, as by adding

wire, the current will be halved. But we should not double the current, by doubling the number of cells in series, though that would double the EMF. In such a case we should also have increased the resistance by the internal resistance of the added cells: if the external resistance were small, the current would scarcely be altered, because it is the total resistance of the circuit which is to be considered, and when the external resistance is small, this resistance is nearly all internal.

Electromotive force is gained by using cells of greater force or by connecting cells in "series," that is + −, + −, which also adds their resistances, and the EMF of a circuit is the sum of all forces thus added, which may be those of various kinds of cells.

Internal resistance is reduced by using plates of large size or by coupling cells together + + and − −, and then to the circuit so as to act as one cell. Different kinds of cells must never be coupled in this manner, though they may be joined in series provided their internal resistance, or capacity to transmit (not generate) current is nearly equal.

174. *Size of cells or plates* has nothing to do with the EMF. Students are often puzzled over this, but a simple experiment will fix it in the mind. Take a piece of copper and cut a piece of several square inches, and also a strip like a thin wire; do the same with a piece of sheet zinc; attach the coppers and zincs to wires and wrap the zincs, after amalgamating them, in several folds of blotting paper. Connect the wires to the terminals of a galvanometer and dip the large pair into a vessel of dilute acid; a deflection will occur, *which will rapidly diminish*: connect the small pair and note how much smaller the deflection, which also will diminish even more quickly. Here we have different quantities or currents arising from the same chemical action, because the larger surfaces enable a greater *number* of equivalent actions to occur: this is called a difference of *internal resistance*. The diminution of the deflection is due to what is miscalled "polarization," the coating of the copper plate with hydrogen, which generates an opposing EMF and so reduces the active force available to produce current. Now dip the plates into a strong solution of sulphate of copper: the deflections will be proportionately affected as before by the size, but (1) they will both be greater, and (2) they will remain steady. The EMF *is greater in this case* by exactly the difference in the energy absorbed from the chemical action by the setting free of hydrogen or copper, § 165. Also as the copper plate is not altered by the coating *of copper*, as it is by that of hydrogen, *there is no "polarization" or counter* EMF generated.

Now join together the wires from the two coppers, connect those from the zincs to the galvanometer, and place the plates in sulphate of copper as before; *no deflection whatever will be seen.* The two actions are opposed: that on the small plates acts as a counter E M F to that on the large plates, and the stress each can set upon the circuit being equal, no current is generated: the condition is something like "consequent poles" in magnetism, § 156, or the hydrostatic paradox, in which a large body of water in, say an open cask, is balanced by a column of equal height in a small tube connected to it.

If now one pair of plates is washed and placed in the acid while the other remains in the sulphate of copper they no longer balance, but a deflection will be obtained corresponding to the difference of the two forces. The two pairs will not balance each other if both are placed in acid, because although they generate equal E M F at the zincs, yet the difference in the areas of the copper plates will result in a different degree of counter E M F set up by the nascent hydrogen.

175. It will be seen that a unit of zinc, in dissolving, must always give the same *quantity* (or current × time) no matter what form of cell it is consumed in. But it may give very different *currents* (quantity ÷ time) and very different E M F according to the nature of the chemical action, for instance, a Daniell cell gives nearly 1 volt while a chromic acid cell gives nearly 2 volts, one unit of zinc dissolved in these would give a voltametric deposit of copper exactly equal from each cell, but the stronger would give it in half the time. Or as the increased E M F would enable a greater resistance to be overcome, a second copper cell might be included in the circuit and a double quantity of copper actually deposited by the one unit of zinc.

176. This agrees, however, with the law of equivalent action, as each galvanic cell must be regarded, for some reasons, simply as a section of the conductor conveying the current; and the first law of the circuit is that the "quantity," and current are equal at every part of the circuit and therefore these can do the same, or equivalent work at every section, provided the E M F or R, permit the necessary current to be maintained.

177. In applying these theoretical principles it must be remembered that electrical operations, like mechanical ones, consist of two distinct parts: (1) the generation or collection of energy from some source; (2) the application of that energy to effect the desired purpose, and this latter is divisible into two parts: that is to say, the conveying the energy to its work, in *which process it is* partially expended, and doing the actual *work. Be the work* we have to do what it may, one universal

law governs all; we must expend, in doing it, energy equivalent to the work, and all the operations incidental to it; under no circumstance will the work do, or help to do, itself; this may seem a mere truism, yet the want of understanding it costs this country many thousands every year. Economy, that is true practical working, consists in obtaining the necessary energy at the lowest cost, and in avoiding all loss in applying it when obtained.

Thus, in ordinary mechanics, it is necessary to select the cheapest fuel, the best furnaces and boilers, then to avoid loss of heat in the steampipes, or undue friction in the engine and connected machinery: at every stage there is room for a wise understanding of principles, and a due application of them. Electrical operations are perfectly analogous and require similar attention. The battery, or other motor, represents the boiler with its fuel, the conducting wires replace the steam pipes, and the work to be done, and apparatus for doing it, are the analogue of the engine and the machinery it may drive; while the steam itself, with its capacity for bearing pressure, and thus conveying the energy derived from the combustion of the fuel, strongly resembles the electric "current," with the various tensions which set it up and give it power.

That form of battery should be selected which best suits the work to be done; for none is perfect, or equally fit for all work. A perfect cell would be one which would contain a large quantity of material in small space; would generate high electromotive force; would not alter its properties during work; would have small internal resistance; and would act chemically only while its electric circuit is closed. These qualities resolve themselves into *capacity for work* and *constancy*.

178. *Capacity for work* depends on two conditions: (1) the amount of active materials contained in the cells, to which is related "quantity" or "current"; (2) the energy liberated by the action, § 158, on which depends the electromotive force.

The first of these is controlled by the size of the cells, and by the solubility of the materials employed; cells are frequently used which are too small, and little regard is paid in proportioning them to their work; this is no doubt due chiefly to a want of consideration of cause and effect. It is impossible for a small cell to work regularly, because the liquid rapidly changes its nature. In double liquid cells care should be taken that the two are so proportioned as to contain the equivalent quantities of the liquids required for the work, so that neither is wasted: sometimes excess of one is necessary to the complete or economical use of the other, in which case the excess should be of the least costly.

179. Generally the elements are best in the form of flat plates, but in many cells they are cylinders; and then the question arises, which should be the outer one, the zinc or the negative? This question may be put in another form: if the plates differ in size, which should be the largest? There are two good reasons why the negative metals should be largest. (1) The zinc is subject to local action, § 183, which contributes nothing to the work, therefore its surface should be limited to the area needed to maintain the desired current. (2) The negative plate is subject to "polarization," and should therefore be as large as possible, § 174. After a great many trials, I have come to the conclusion that the best arrangement is to fix the negative element as a cylinder, in the middle of which the zinc can be suspended.

180. *Constancy* means, that having once set up a battery under certain circumstances, giving a certain current, then that current shall be steadily maintained till the materials of the battery are exhausted. Of course, the conditions assume that the external resistance remains unchanged; therefore, inconstancy, or fluctuation of current, may arise from variation in either the force generated, or in the internal resistance of the battery. The latter change occurs to some extent in all cells from the formation of sulphate of zinc, and the former occurs in most in consequence of so called "polarization," § 174.

A battery which would at all times, and under all variations of external work, generate a uniform electromotive force would be invaluable; but none such exist. The Daniell, § 205, is the nearest approach to it, and the Grove, § 226, the next.

Duration is quite distinct from constancy; it depends entirely on the cell containing materials enough to continue working the required period; this is a function mainly of size of cell, as related to the required work, as explained § 178.

181. *Density of current.*—This means the quantity of current related to the surface area of a conductor, such as the plates of a cell. Theoretically, current is proportional to E M F, but every reaction has a particular rate beyond which it cannot be pressed without introducing new conditions. Thus the rate at which zinc can be consumed in acid will depend upon the strength of the acid, and the deposit of copper can only proceed at such a rate as the diffusion of the liquid will bring fresh copper salt to replace that which is reduced: so with every action there is a *maximum rate of* proper working, and if an external E M F, *such as that of other* cells in a battery, presses the action

beyond this limit, a counter E M F results: therefore no cell can advantageously form part of a circuit transmitting a larger current than the cell would itself generate on *short circuit*, that is with no external circuit; and the most advantageous current a cell can be called upon to produce is half of its short circuit power. See also § 173.

182. ZINC.—This is practically the only positive metal employed; iron is sometimes recommended by those who do not understand what is true economy, but its E M F is only two-thirds that of zinc, so that its use involves extra cells in that proportion, and waste of the chemicals, which usually cost more, per unit of current, than the zinc.

Cast zinc is not so good as rolled, it is hard to amalgamate, and has less electromotive power, but for rods for use in porous jars, and particularly with saline solutions, cast zinc is commonly used. In this case, care should be taken to use good zinc cuttings, removing any solder, and using a little nitre as a flux, which will remove a portion of the foreign metals. It is well, also, to make the thickness greater towards the bottom, and in casting, to add a little mercury to the metal just before pouring.

It is stated that zinc alloyed with a little tin, lead, and antimony, works better than pure zinc, but it seems improbable.

Rolled sheet zinc, from one-sixteenth to a quarter-inch thick, suitable for cylinders and plates, costs about 4*d*. per pound. The simplest way to cut it to size is to scratch a groove with a steel point, such as a bradawl; run first acid solution, and then mercury along this groove, and allow it to penetrate; then repeat the process on the other side, when the metal is easily broken: it may also be cut with a handsaw. Zinc softens with moderate heat, so that hard and brittle as the metal is, it can easily be bent up into small cylinders, if held in front of a good fire till too hot to handle with the naked hand, and then bent round a piece of wood or metal.

As the zinc is eaten away at the surface line of the liquid, it is well to coat that part with a varnish, or paraffin wax.

183. *Local action.* Zinc in acid is consumed in two ways as shown, § 162. It is only that action which sends the hydrogen to the negative plate which is useful, as supplying E M F; any gas given off at the zinc is wasteful consumption, but it cannot be wholly avoided. Pure zinc is, however, very slightly acted on, except when the conducting circuit is closed, while ordinary zinc is continuously dissolved. This difference is usually attributed to the *presence of foreign* metals setting up little *local circuits: and, therefore, this* waste action is called "local

action." It was discovered by Sturgeon that common zinc, when amalgamated with mercury, is not much acted on, and this seems to render this explanation somewhat doubtful. However a well-amalgamated plate is scarcely acted on in dilute sulphuric acid, but the presence of nitric acid, or metallic salts, does away with the protection, which appears to depend chiefly on the adhesion of a film of hydrogen gas to the surface, which prevents contact with the liquid. When the circuit is closed the hydrogen is transferred to the negative plate, and the protection is removed. Amalgamation also renders the zinc a better source of electricity, as it is more positive than ordinary metal. Zinc should always be well amalgamated for use in cells with acids; but it is of less consequence in presence of saline solutions.

184. AMALGAMATION.—Care should be taken to use only pure mercury; much of that sold contains lead and tin, which are mischievous. The mercury should be kept for some time in a bottle, with dilute nitric acid over it and occasionally shaken up. To amalgamate zinc, wash it first with strong soda, to remove grease; then dip it in a vessel of water containing one-tenth of sulphuric acid, and as soon as strong action takes place transfer it to a dish (such as a soup plate): pour mercury over it, and rub it well till a bright silver-like film forms; then set it up on edge to drain, and before use rub off any globules which are set free. Whenever the zinc shows a grey granular surface (or rather before this) brush it well and reamalgamate, remembering that saving of mercury is no economy, and free use of it no waste—for it may all be recovered with a little care. Keep a convenient size vessel solely for washing zincs in, and brush into this a dirty grey powder which forms and is an amalgam of mercury with zinc, lead, tin, &c., and forms roughnesses which reduce the protection of amalgamation. This washing should be done whenever a plate is removed, and never less than once a day if in regular use; the fibre brushes sold at 3*d.* and 4*d.* as coarse nail-brushes are excellent for these purposes, but of course must not be left soaking with acids. Let the powder collect for a time and then transfer it to a bottle, in which wash it with sulphuric acid first, and then with dilute nitric acid, and you will recover the mercury; or the dried powder may be mixed with a little salt and distilled over from an iron retort into water.

185. *Permanent amalgamation* may be maintained by attaching a small shoe of gutta-percha, containing mercury, to the foot of the zinc plate: the mercury continually creeps up the surface kept clean by the action. This plan though commonly used

very many years ago, has been re-invented of late, and called by several inventors' names.

Zinc eats into hollows while dissolving, and it is good economy, to fill them up, when cleaning, with an amalgam containing as much zinc as possible, well forced in.

186. SULPHURIC ACID.—This is the most important excitant used in ordinary batteries. Real O. V. (oil of vitriol) has a specific gravity of 1·845, and contains about 99 per cent. of the true acid (H_2SO_4): it is of a clear colour, and has an oily appearance: this is the acid always meant when sulphuric acid is spoken of. Brown oil of vitriol is the ordinary product of the chambers, or this boiled down in lead pans, and contains variable quantities of acid. This is a question of price only, but this acid often contains impurities of serious consequence.

Brown colour may be due to dissolved organic matter, straw, &c., and is of no moment.

Arsenic is often present, and must be strictly avoided, as it unites with the hydrogen given off, forming a deadly poison when strong, and being in any case injurious to health. It is detected by diluting the acid, and passing sulphuretted hydrogen: arsenic forms a yellow precipitate.

Lead is often present as sulphate, and must be carefully removed, or it will deposit on the negative metal; it is only necessary to dilute the acid in a separate vessel, allow it to cool, and filter it off before use.

Nitrous acid is often present and wastes the zinc by destroying the hydrogen film, but is otherwise of no consequence.

The addition of a half per cent. of colza, or other oil to the acid before dilution, shaking well together, precipitates the metals as soaps, and forms a sulpho-glyceric acid which is said to protect the amalgamation.

The strength of acid used in batteries may vary from one-twentieth to one-tenth by measure of acid to water.

TABLE II.—SPECIFIC GRAVITY OF SULPHURIC ACID.

One-twentieth, volumes	1·055	70 per cent.	1·598
One-tenth "	1·100	80 "	1·708
One-third "	1·259	90 "	1·807
50 per cent. weight	1·388	100 "	1·846
60 " "	1·486		

The third line is that strength which has least resistance, and may be used in voltameters. Very strong acid cannot be used in batteries, as there *must be at least* water enough to dissolve the *sulphate of zinc as formed.* A good solution is made by mixing 1 part by bulk with 10 of water, which should be soft, as water containing lime is apt to form a deposit on the metal surfaces; if hard, it should be boiled before use. 100 grains by measure of such a solution will dissolve about 11¼ grains of commercial zinc; but it is bad economy to nearly saturate the acid, particularly if several cells are combined in series, as zinc is apt to be deposited on the lower part of the negative plate which is thus destroyed for the time, and from which, as the zinc is pure, it is a troublesome process to dissolve it. But allowing for impurity in zinc, local action, and a due proportion, or about one-fifth of free acid left, one pint of this solution would dissolve about 1¾ oz. of zinc. We may thus calculate the work a cell is capable of doing as about equal for each pint of solution to 24 equivalents or units, and the cost per unit of the single acid cells (line 27, Table V.) ·0438 of a penny, taking amalgamated zinc at *6d.* per lb.

187. HYDROCHLORIC ACID.—This will serve equally as well as sulphuric, but is seldom used because it is dearer; it also evaporates and gives off injurious fumes and generally contains a little iron. But it has advantages; it gives about 5 per cent higher E M F than H_2SO_4, besides which the chloride of zinc formed is very soluble, and will not creep up the cells and crystallise as the sulphate does; also it is useful as a soldering flux and a disinfectant.

188. SALINE SOLUTIONS.—These are sometimes recommended, but are useless in single-action cells. They are useful in such forms as the manganese cells, where oxygen is provided to take up hydrogen. Sulphate of zinc is very useful in place of acid in the Daniell, as the sulphate of copper supplies the needed acid; but it is not good in nitric acid cells, as that means solution of the zinc by the more expensive acid. Common salt has often been suggested, but is very injurious, as it forms insoluble oxychlorides; the same applies to sal-ammoniac (ammonium chloride) except in the manganese cells. The salts all create a much higher internal resistance, and therefore waste the energy.

189. CAUSTIC ALKALIES.—These dissolve metals and may be used instead of acids: thus zinc, lead, and tin are soluble in caustic soda and potash, producing materials useful in dyeing and other arts, and batteries have been used in which they are substituted for zinc, which is also used in several forms to be described later. Copper is soluble in ammonia, producing a compound (cuprammonium) which has the property of dissolving cellulose. Caustic alkalies or their carbonates separated from acids by porous cells generate E M F by their reaction,

even with plates of similar metal, as platinum, and this may be added to the force arising from their separate relations to different metals. The objection to alkalies is that they absorb carbonic acid from the air, which may be largely prevented by covering with a stratum of paraffin oil. The metal also continues to dissolve when the cell is out of action, but does not need amalgamation.

Soda solution is prepared by boiling 1 lb. common washing soda in 4 pints of water with 6 ounces of quicklime reduced to a cream with part of the water. The boiling should be effected in an iron pot not tinned, and continued as long as the clear solution effervesces on addition of acid. It can be separated from the carbonate of lime by settlement and pouring off, and, if desired, boiled down to dryness for keeping. The solution of potash gives a higher force than soda, but is more expensive.

190. *Zinc in alkali* may be recovered where the quantity makes it worth while. If sulphuretted hydrogen is passed through the solution, the zinc is thrown down as a sulphide more or less pure, and the caustic alkali is reproduced ready for use again. The sulphide of zinc may be used as a paint or purified by dissolving in sulphuric acid, giving off H_2S, which can be used to throw down another charge, so that the first supply of H_2S serves continuously. The sulphate of zinc after being freed from iron by a little bleaching powder, can now be precipitated with barium sulphide, a cheap natural substance, which produces a mixture of sulphate of barium and sulphide of zinc, which is an excellent white paint.

The last part of the treatment applies also to solutions of zinc sulphate obtained from acid batteries.

191. The simplest galvanic generator, and the first devised, is the combination of alternate plates of copper and zinc. Most electrical works employ a good deal of space, in describing the forms devised by Cruikshank, Wollaston, and others, consisting chiefly of the mode of arrangement in the containing vessels, the use of double copper plates surrounding the zinc, and such like matters. But, as the simple copper-zinc arrangement is the most unsatisfactory form known, this couple calls for attention simply for the sake of principles.

COPPER AND ZINC.—When the plates are first immersed in dilute sulphuric acid, and the wires connected to a galvanometer, a deflection is produced, marking a powerful current, but the effect rapidly decreases, §§ 162 and 174; after a time the copper is coated with a film commonly said to be oxide of copper, though it is obvious that no oxide could form there in the presence of nascent *hydrogen; it is* really a combination of this hydrogen with the metal, and the diminishing power of the cell is due to the formation of this hydride or alloy, which prevents contact of the copper with the liquid, thereby increasing the internal resistance, while the affinity of the hydrogen for the acid radical resists the polarising power of the zinc and diminishes the electromotive force of the cell, § 174. This rapid failure will be seen in Table IV.

Pure copper, as deposited by the electrotype process, has a higher power, probably because of its purity, but also on account of the nature of its surface, which is covered with innumerable fine points, from which the hydrogen is given off more readily than from a smooth surface. Hence, if a copper negative plate is to be used, it should have a deposit of copper formed on it. A little nitric acid added to the solution (or even nitrate of soda) greatly increases the efficiency, but in this case a porous cell is desirable to keep the zinc apart.

192. IRON AND ZINC.—Iron has often been recommended as a negative element because its surface keeps clean. Its force is very low, as may be seen by Table IV. The reason of its surface remaining clean is mainly that the acid acts upon it as well as on the zinc, and thus causes much waste.

193. SILVER NEGATIVE.—This acts very well, especially if a thickish deposit is formed upon a thin sheet, so as to obtain a rough surface. Such a coating may be deposited on copper, but deposited metal is always porous, and the acid eventually acts upon the copper; this is the only objection to the use of copper-wire gauze plated, which otherwise makes an excellent negative; it should never be left in the acid when out of action.

194. PLATINISED SILVER.—Smee having found that the nature of the surface was of the greatest importance, and that the hydrogen is more readily given off from a rough surface than a smooth one, and also bearing in mind that platinum has the highest electromotive force of all the metals as opposed to zinc, deposited this metal as a fine black powder on the surface of silver, and the cell with this as the negative plate, which justly bears his name, is one of the most valuable gifts ever made to electrical science. But even this cell rapidly fails, if worked with a full current. The Smee battery, in its usual form is of simple construction; the silver sheet is held in a saw-cut down the middle of the inside surfaces of a wooden frame, of which the top and bottom bars may be $\frac{3}{4}$ inch thick, and the sides $\frac{3}{8}$, the wood being well baked and soaked in melted paraffin before *putting together* by the usual mortises and tenons; a sheet of *zinc is held on each* face by means of a brass clamp with a screw,

which presses them against the frame, and carries also the binding-screw for the connection, that for the silver passing through a hole in the top bar, and being soldered to the silver; the zincs should be narrower than the silver, in order to give free escape for the [illegible]

195. Rolled silv[illegible] obtained ready platinised, or ordinary thin sheet can [illegible]tly roughed with fine glass-paper, or by dipping in nitric [illegible] well washed and platinised. Insert in a vessel with dilute acid, and connect it by a wire to a small slip of zinc in a porous vessel in the same acid; in fact mount it as a battery, but exposing at first only a mere touch of the zinc to the liquid; drop in a few drops of platinic chloride, and stir; gradually a faint colour forms on the silver; add more platinum salt, and increase the zinc surface; and after a good adherent coat is formed, gradually increase the action till the surface is fairly covered with a black coating, which touch as little as possible. The platinum solution is made by dissolving scraps of thin platinum in a mixture of two parts of hydrochloric and one of nitric acids; the solution is very slow, and is best effected in a flask with a long neck, in which is inserted a test-tube filled with water, and stood by in a warm place.

Substitutes for silver have often been proposed, as lead, and an alloy of lead, tin, and antimony; they are all bad economy, as they give lower E M F, and silver has a value of its own, even when worn out.

196. CARBON AND ZINC.—Mr. Walker suggested the use of graphite plates; it has also been platinised, which increases its power. Owing to the greater resistance of carbon and its power of condensing hydrogen, this combination gives a lower current than a silver plate of the same size, and has various inconveniences which render it less economical in the end than silver.

197. For occasional purposes, or for large working, the best construction is to use a jar or wide-mouthed bottle with the negative element as a large cylinder, supported in it by wires well coated with cement and provided with a binding screw. The top can be closed with a piece of baked and paraffined wood with a hole in the middle which will just admit the zinc plate or rod to be passed in when required; at other times this opening can be stopped to prevent evaporation.

198. A similar arrangement can be made with a porous jar fixed in the top, and this may contain a saline solution to diminish action on the zinc. There must be an opening in the top, outside the porous jar, *for the* purpose of changing the liquid *and allowing gas to escape.* If the part of the porous

jar above the liquid be well soaked with paraffin (or if merely a glass tube passes down to below the surface of the liquid), the cell becomes an admirable voltameter, if a small tube is fixed in the top to carry the gas away to be measured.

199. For large currents, wooden cells lined with cement are used in which plates are suspended, alternately zinc and negative metal, all of each kind being connected together (one connection on each side of the cell is best) to act as one element of large surface.

An excellent mode of making connection to the zincs is to have a narrow trough containing mercury across the bottom of the cell, connected by a wire covered with acid-proof cement, so that standing the plate in the trough connects the zinc at once, and also keeps up its amalgamation §185; a bar should be provided for the zinc to lean against. Each zinc, for regular working, should be in the form of at least two plates; one of them can then be removed and replaced by a fresh plate without deranging the work going on.

200. *Odds-and-ends Cell.*—Smee proposed what he called an "odds-and-ends" cell, composed of a jar in which a quantity of mercury was placed with scraps of zinc, broken plates, or even raw spelter; a plate of platinised silver was then suspended in the jar and the acid solution added. It is not satisfactory, but may be used to work up broken plates and ends; such a cell as § 197 may serve, with a porous cell, or even a gutta-percha or earthenware one with the sides full of holes, fitted with a connecting wire (§ 199) and a layer of mercury. Or a square cell, with a division across the bottom, forming a mercury trough, may be used, the – plate hanging clear of the mercury. The mercury is subject to little waste, but now and then the whole should be removed, well shaken up together, and repacked, and the mercury, as it becomes charged with metals, should be filtered by squeezing through a wet chamois leather, the residue being added to the collection described § 104.

201. All these single liquid cells have two defects: (1) As the energy is largely carried off by the hydrogen, their electromotive force is low; it cannot exceed 1·1 volt, and in actual work its rarely exceeds ·5 volt. (2) deficient constancy, as shown in Table IV., which can only be partially overcome by largely increasing the negative surface.

202. Depolarizing Batteries.—This is the name frequently given to those in which some agent is employed to prevent the hydrogen from being set free. There are two modes of effecting this:—(1) a metallic salt allows its base to be thrown down, it being replaced by the hydrogen which forms an acid; (2) a

substance is used which contains oxygen or chlorine in a combination easily released. and with which the hydrogen can unite. This is effected by *liquids*, such as nitric or chromic acids which are powerful oxidants, or by *solid oxides*, such as peroxides of manganese or lead.

Inventors have given much attention to these combinations, and there are a multitude of batteries named after their inventors and patentees. Few of them are of any value, and most of them are reintroductions of matters thoroughly known 30 or 40 years ago: others are modifications of construction. It would be impossible to describe all of these, but those of most probable use will be explained. Readers will be best served by having the principles explained which govern them all and the best modes of construction pointed out. When two liquids are required, they must be kept from mixing, so far as possible, without destroying the continuity of liquid by which conduction is effected.

203. Porous Jars.—At first, animal membranes, bladders, ox gullets, &c., were utilized. In some cases good paper is useful, especially the parchmentised paper. In experiments requiring great resistance, glass tubes plugged with plaster of Paris, or even clay, are employed; for small experiments, or for platinising silver, the bowl of a tobacco pipe may be used. For practical purposes unglazed earthenware is employed, and may be obtained in any form or size. There are many qualities, and they must be adapted to the special purpose. These porous jars conduct by the liquid they absorb, and as they reduce the area of liquid through which the action takes place, they increase the internal resistance; nor is it possible to prevent some mixture of the two solutions thus separated, which causes waste by local action, besides affecting the regularity of the working. Hence for long-sustained action a thick and close-grained jar must be used, while an open and more porous one suits best for short periods and strong action. The most porous ones are of a red colour and soft material, the finest and most enduring are close-grained and white; a good material is soft, and may be scraped with a knife. The best test is to fill them with water and see how long it is before it forms a dew on the outer surface; if it runs off, the jar is not fit for use. It is a great improvement to render the bottom, and still more the part which is to remain above the liquid, non-absorbent. If this is not done the salts rise up, effloresce, crystallise, and disintegrate the jar. For the same reason jars taken out of the liquids must not be permitted to dry, but should be kept soaking in water to prevent their destruction. This is of particular importance with jars used for

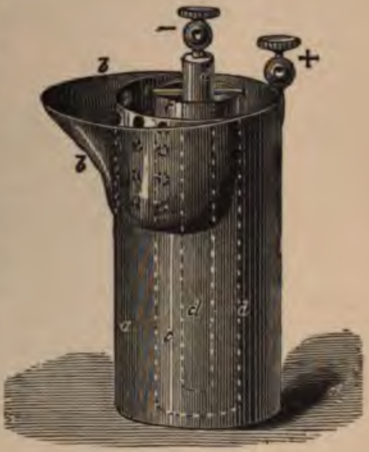
the Daniell's cell, as they are very apt to get nodules of copper deposited on them wherever the zinc has touched the inner surface, particularly at the bottom, where drops of mercury or flakes of zinc fall, and the cell is very soon rendered worthless; if this occurs, the spot of metal should have some cement or gutta-percha laid over it, so as to render it non-conducting. Some porous jars are glazed at the upper part; when this is not the case they should be rendered non-absorbent by standing in a thin layer of paraffin kept just above its melting point, till this has been soaked up as far as is required.

204. ELECTRIC ENDOSMOSE.—Whenever two different liquids are separated by a porous diaphragm they each pass over into the other, and become mixed: this action is called *endosmose* and the sole use of the diaphragm is to diminish the rate of mixture. This action occurs in both directions, but when an electric current passes through liquids thus separated, the liquid travels with the positive current, with such a force as to counterbalance a large difference of level. I have known zinc cells to be nearly emptied, when a strong current was passing. It appears as though the actual substances undergoing decomposition were not the pure bodies, but compounds of these with water, and that this accompanies the + ion: but it is also found that the bulk carried by a current is greater with badly conducting solutions than with good conductors. The laws ascertained by Weidemann are: (1) the quantity which flows out in equal times is directly proportional to the strength of the current. (2) The quantities flowing out are, all other conditions being equal, independent of the size of the porous substance. (3) The height to which a current will cause a liquid to rise is directly proportional to the extent of the porous surface. (4) The force with which an electric tension urges a liquid across the partition is equivalent to a pressure proportional to that tension.

205. THE DANIELL'S CELL.—This, the first devised improvement, is also the most successful attempt to obtain constancy. To it also we owe the discovery of the electrotype process. Its principle is, that copper, as the negative metal, is surrounded by a solution of a salt of copper, which is reduced; instead of hydrogen, copper is set free, and deposited on the negative surface which is thus kept constantly renewed. The acid of the salt is transferred by electrolysis to the positive metal, through the porous medium; hence if fresh salt is provided to replace the consumption the negative plate and solution remain *unaffected* except by endosmose from the zinc cell, but still *absolute constancy* cannot be obtained, because as the zinc

dissolves, the solution belonging to it becomes less active and less conducting. The great drawback to this cell is that the copper salt passes by *endosmose* into the zinc solution, and acts on the zinc, where the copper is deposited, and causes great waste by setting up local actions. Many forms have been devised to prevent this, some of which will be described. A plan I have found to answer with large cells for long-continued experiments in which constancy was important, is to use a larger porous jar outside the zinc one, filling the space between them with a strong solution of zinc sulphate, and some zinc cuttings to decompose any copper salt entering; the inner cell is thus kept nearly free, but of course the internal resistance is somewhat increased. The ordinary form of the Daniell is shown in Fig. 35: *a* the copper vessel fitted with a reservoir *b* for the crystals, *c* the porous cell, *d* the zinc rod suspended in it by a bar passing through it. The part of the copper cylinder within the reservoir is of course perforated, and should be well varnished. Modes of construction may be varied to any extent. Thus instead of a copper containing vessel, a glass or earthen jar may be used with a cylinder of sheet copper, or such a jar may be covered inside with a film of wax, blackleaded, and the deposited copper will form its own surface, or thin sheet lead may be used (not tin). As the copper solution creeps up the surfaces (especially with glass) the upper part of the vessels should be warmed, and coated with paraffin, which resists this action.

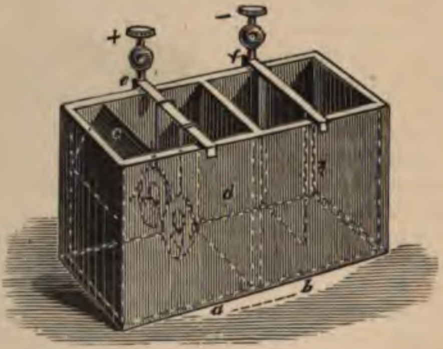
Fig. 35.



206. Flat plates may be used in a vessel across which a plate of porous material is fixed, and this has advantages; among others it is easy to make the cell itself serve as a depositing vessel by using models, seals, &c., in fact any object we wish to copy, as the negative surface, by suspending these to a rod which forms the + pole of the battery. This is in fact what is called *the single-cell process of electrotyping*. The cell is best

made of wood, lined with a resinous cement; gutta-percha may be used, but has the disadvantage of facilitating the *creeping* process of acids and salts, which is troublesome and messy, besides causing loss of power. Four parts resin melted with one of gutta-percha, and a small quantity of boiled oil answers perfectly; the wood should be perfectly dry and warm when it is applied. A similar cement with a larger proportion of gutta-percha may be used for covering wires, first heating them so as to insure adherence; for this purpose it should be run into sticks. Such an apparatus is shown in Fig. 36: *a b* is the box divided by the porous partition *d*, which may be replaced by a porous cell standing in the box: *c* is a place for holding the crystals; *e* and *f* are two bars of metal, to which are hung the objects to be copied and the zinc plate, each fitted with a binding-screw. The bars being movable, it is easy to regulate the distances, and so to control the action, by altering the internal resistance.

FIG. 36.



207. This apparatus answers admirably for a voltameter by using a light copper plate and weighing it after an experiment. The Daniel cell will also serve as an approximate measurer of current by the solution of the crystals. As these contain one-fourth their weight of copper, the quantity needed for a given work is easily calculated, and if this is put in the reservoir, when dissolved it will indicate the completion of the work. Sulphate of copper is often very impure, iron and zinc replacing the copper, and therefore the salt should be examined.

208. The fluid surrounding the zinc may be the usual acid,

but for constancy, though with somewhat greater internal resistance, the best solution is a half saturated one of sulphate of zinc, kept in proper condition by occasionally removing a little and replacing with water. Sal-ammoniac or common salt have been used, but see § 188. With neutral solutions the zinc need not be amalgamated: the zinc should be removed occasionally and the deposited copper brushed off, and when a battery is required only at intervals, the zinc solution should be emptied into a jar with a few scraps of zinc to reduce any copper. As during action the current resists the endosmose of the copper towards the zinc, § 204, it is desirable, when a battery is out of action, to close its circuit through a resistance, so as to maintain a small current. In fact it is found with the Daniells used in telegraphy, consisting of porous cells greased everywhere except upon a surface sufficient to allow the required action, that the expense of maintenance is about the same, whether working or not.

209. The action of the sulphate of copper cell is easily explained as an extension of that shown Fig. 34, § 167. If we consider the two molecules to the right to be sulphate of copper,

$$\begin{array}{ll|ll|lll|l}
\text{We have,} & & \overbrace{H_2SO_2,} & \overbrace{H_2SO_4} & \overbrace{CuSO_4,} & \overbrace{CuSO_4,} & & \\
\text{polarized} & \text{Zinc} & \overbrace{SO_4H_2,} & \overbrace{SO_4H_2} & \overbrace{SO_4Cu,} & \overbrace{SO_4Cu} & & \text{Copper.} \\
\text{breaking up} & & \overbrace{ZnSO_4,} & \overbrace{H_2SO_4.} & \overbrace{H_2SO_4,} & \overbrace{CuSO_4,} & Cu &
\end{array}$$

The last line shows that an atom of zinc is taken up and one of copper displaced; that the force is the difference between the affinity of sulphuric radical for zinc and for copper; the acid serves only as a conductor, as it will be seen that there is the same quantity after action as before; the force is equivalent to the heat zinc would give while precipitating copper from its sulphate, and is really the difference between the energy existing in sulphate of copper and that necessary for sulphate of zinc.

210. *The Electromotive force of the Daniell.*—It is usually stated to be volt 1·079, but is subject to many causes of variation, so that good authorities differ as much as 3 per cent. in the value. Dr. Alder Wright calculates it from the chemical reactions as 1·105 and says that the specific gravity of the liquids, i. e. the strength of the acid, plays so important a part that with acid, specific gravity 1·010 the E M F is 1·123; at 1·050 it is 1·133; and at 1·090 it is 1·143. Other authorities say that with sulphate of zinc it is 95 per cent. of that with acid. My own

experiments indicate that there is not much difference due to this cause. I found that in such delicate experiments where no real working current is developed, what is measured is really static potential rather than E M F; the mere motion of the zinc plate, or brushing off the bubbles of hydrogen would make an instant change of 3 per cent. and that therefore this action alone, if unknown (and I have never seen it noticed), would vitiate many observations.

211. Dr. Wright states "it was found that but little difference was produced by using pure, commercial or amalgamated zinc, or zinc coated with a film of copper." This is different from the received opinions, and from my own experience. I find that amalgamated zinc has the higher force by about ·01, as compared with new sheet-zinc, and more as against corroded zinc, and that the E M F of any zinc plate is always increased by cleaning off the residuary impurities, and renewing the amalgamation.

The effect of copper deposit on the zinc is very marked, and may be easily tested; if the zinc plate be touched with a copper wire the force falls ·03. This is not, as sometimes said, an effect of *contact* lowering the potential; it is a direct chemical action: there was already a copper contact in the wire conductor soldered to the zinc; in fact, merely touching with copper out of the liquid produces no effect; the copper must be under the liquid so that it sets up a local action. I found that by adding copper sulphate to the zinc solution, to throw down copper on the zinc plate, the force fell ·03, and then touching with copper produced no effect. It is evident therefore, that where a constant E M F is desired, the zinc plate used should not be free from copper. But all loose deposits of copper should be removed at intervals.

212. *Variation of temperature affects the E M F.*—Heat raises the force; it does so by affecting the solubilities of the two salts, and supplying externally the energy absorbed in solution. I find that between 32° Fahr. and 52° there is a difference of volt ·01 and between 50° and 60° also ·01, and between 50° and 100° about ·025.

213. These experiments were carried out by means of cells consisting of U-tubes; the bends of which contained sand mixed with oxide of zinc, to prevent passage of the copper salt. I found these remained in perfect action for a week without a trace of copper passing; the tubes were mounted in stands with mercury cups, and the plates of metal had wires attached, so that they dropped into the cups as the plates were inserted in the tubes, and could be readily exchanged. Of course the

object in such experiments is to isolate each action and obtain theoretical perfection at the moment, in order to ascertain whence come the defects which arise in more practical operations.

214. It is generally considered that the Daniell is not subject to "polarisation"; that is to say, that its E M F is constant whatever the external resistance may be: this is not exactly the case: it is affected by the "density of current" derived from it. According to Dr. Wright a surface of 125 sq. centimetres (19·5 sq. inch) will maintain its E M F up to a current of ampere ·001′, and will lose 1 per cent. if called on to produce ·006 and as much as 10 per cent. if worked to ampere 0·4. These figures are, however, entirely special, applying to a particular construction. The cause at work is very clear; it is, that the current developed must be proportioned to the supply of copper salt presented to the copper plate: if the solution is not strong enough to meet the demand, we have copper, not in copper salt, but in sulphuric acid, because the copper has been removed from the molecules adjoining the plates: this can only be corrected by the process of diffusion.

215. *The Daniell Cell* has been fully examined because of its importance, both practical and theoretical, and it only remains now to show the cost of its working. In this instance, this is shown in full detail, and will serve to show how the cost of the other forms has been arrived at in Table VI.

The local action will depend on the quality of the porous vessel, rate of working, &c., but we may allow 5 per cent. We have then per unit, by Table V.:—

Line 24	Zinc unamalgamated	·0195
" 9	Copper sulphate	·0900
	Local action	·0055
		·1150
Less 8	Copper reduced	·0566
	of a penny ..	·0584

This assumes that zinc sulphate is used in the zinc cell and costs nothing, it being a product of the working. The reduced copper is taken at the common value, but if it is deposited in useful forms the actual cost of the cell will be reduced to nothing in many cases, and it is so worked in some factories, where large cells are so arranged that the copper plates are objects receiving deposit, such as stereotype blocks, while current is led from them to other work.

216. THE GRAVITY BATTERY is a Daniell without a porous cell, in which the copper solution is kept from the zinc only by its greater specific gravity but gradually reaches it. There are many forms, but it was first proposed by Mr. Varley.

In *Callaud's*, used in American telegraphy, the bottom of the jar is covered with a sheet of copper fitted with a wire conductor, upon this is laid a stratum of crystals of copper sulphate, which should be large if a small current is wanted, small when much work is to be done; the zinc plate is suspended above and the jar charged with water, or a weak solution of sulphate of zinc; it must of course be placed where not subject to vibration.

Large cells of this kind have answered well, where large and *constant* currents are needed.

It is advantageous to enclose the zinc in an envelope of parchment paper or close cloth, and also to cast it in a conical form to allow any gas to escape. The crystals should also be somewhat raised above the copper, in a tray with a bottom full of holes, or made of horse hair cloth, and covered with a similar material.

217. *Central reservoirs of crystals.*—Instead of a stratum of copper sulphate on the bottom, a tube or funnel may occupy the middle of the vessel and contain a supply of crystals, while the zinc is a ring around the tube. In some cases the bottom of the tube is closed with a cork containing a glass tube of such size as to limit the outflow of the saturated copper solution: and it is preferable to add another bent tube rising inside to the crystals, and outside to nearly the surface, so as to act as an inverted siphon and draw off the upper part of the solution.

The most satisfactory arrangement I have been able to devise after many trials is one of this character in which the opening of the outflow tube is fitted with a plate of soft india-rubber which can be pressed up to and close it when the battery is not wanted for action: it is desirable also to close its circuit through a considerable resistance at such times, so as gradually to use up the copper solution.

The *Meidinger cell* is on the same principle; the reservoir of crystals is a flask, the neck of which replaces the tube just described; being closed from atmospheric pressure, the supply of solution is very gradual, like the bird fountain. All of these work best for a gradual demand, but do not answer well, if left out of action for some time, and then called on to supply large current.

218. The *Minotto* has been much lauded; it consists of a jar, *at the bottom of* which is a copper plate, fitted with a wire,

covered with an inch of crushed sulphate of copper, and a layer of silver sand which is to act as the porous division. Some use sawdust instead of sand, others paper pulp, or felt; they are useful where great internal resistance is not an objection but the copper inevitably finds its way to the zinc. A layer of oxide of zinc on the top, with the zinc plate laid on it, is the best protection against this.

219. *Caustic soda* was used by Regnier, instead of acid in a Daniell: he used a special porous jar made of parchment paper: for slow work against large resistance it might be useful, as the pores of the porous jar fill with a hydrated salt of copper which, while resisting endosmose, permits of electrolysis.

220 SULPHATE OF MERCURY.—This was introduced by Marie-Davy, chiefly for producing small intermittent currents of great EMF (1.5 volts). His cell is a zinc and carbon pair, the latter of which extends to the bottom of the vessel and dips into a mass of the sulphate. The vessel is then charged with water, which dissolves a small portion of the salt slowly, and this sustains the action, the acid radical acting on the zinc, the mercury depositing on the carbon, from which it falls and collects as metal at the bottom. The action can, therefore, only be sustained at the slow rate at which the salt enters into solution. It has gone out of use because the manganese cells answer the practical purposes to which it is adapted, and the chloride of silver is better for scientific uses.

221. SANSCHIEFF'S BATTERY.—This is a reintroduction of the Marie-Davy, made more practical by the use of a more freely soluble sulphate of mercury enabling much larger currents to be produced, with a small internal resistance. Of course the solution can be used in any convenient form of apparatus, those designed by Mr. Sanschieff, having their details well worked out.

The solution is prepared by adding 3 parts by weight of water to 1 part of basic sulphate of mercury, and adding strong sulphuric acid drop by drop, till the sulphate dissolves and a fresh precipitation commences.

222. CLARK'S MERCURY CELL.—This was devised by Mr. Latimer Clark, not as a working cell, but as a standard of electromotive force, to compare with other cells by means of condensers or electroscopes, it having a constant electromotive force, which the most recent determinations give as volt 1·4346 at 15° C. It consists of a layer of pure mercury as the negative plate, connected by means of a platinum wire in a glass tube. On this is laid a *paste of* mercurous sulphate, which has *been boiled in a thoroughly* saturated solution of zinc

sulphate; the positive element is a plate of pure zinc resting on the paste. Mercurous sulphate, Hg_2SO_4, can be made by heating 1 part of mercury in 1½ of oil of vitriol, taking care that the heat does not rise to the boiling-point, which would produce mercuric sulphate $HgSO_4$. The mass is to be washed with cold water as long as an acid reaction is shown. If any mercuric sulphate is present, a yellow colour will be produced, and the substance should be rejected. In fitting up the cell, it should be warmed with the mercury in it, and the paste inserted after boiling to expel air. The zinc is then placed in it, and melted paraffin poured on to exclude air. A cell intended to serve as a standard of E M F should never be allowed to pass a current; with this precaution it will be fairly constant. Heat decreases the E M F about ·06 per cent. per degree Cent. for about 10° above or below 15° C. Below this and towards 0° C. the E M F increases ·08 per degree.

223. CHLORIDE OF SILVER CELL.—This is a wire or plate of silver, upon which chloride of silver has been melted as a coating of "horn silver," in a solution of zinc chloride, and is much used to work small pocket coils for medical purposes.

The freshly-dried chloride of silver can be fused over a gas-burner in a porcelain dish or crucible, and the silver dipped into it; after receiving a film, it is removed to cool and re-dipped till a sufficient coating has adhered. This is usually wrapped in blotting-paper and a zinc plate pressed against each side. The plates are often attached to a cap, which screws on the top of an ebonite case. They are to be dipped occasionally in a weak solution of chloride of zinc.

The chloride may also be used as a powder, in the same way as the sulphate of mercury in the Marie-Davy, or it may be mixed with powdered graphite, and used in a porous cell with a plate of carbon.

The reaction is reversible and might be used in a secondary battery; but, as in many cases of electrolysis of chlorides, a considerable quantity of oxychloride is produced, which is not readily reduced again.

224. De La Rue's cells are composed of a cylinder of chloride 2¼ inches long and ⅓ of an inch thick, cast upon a flattened silver wire, and wrapped in a tube of parchment paper. The wire passes through a stopper of paraffin wax (which also carries a small zinc rod) inserted in a test-tube 1 inch in diameter and 5½ inches long: the solution is ammonium chloride 200 grains to the pint of water. The E M F is 1·065 volts, and the resistance 3 to 4 ohms, increasing as oxychloride forms on the zinc sometimes to 30 or 40 ohms. This deposit can be removed

by dipping in dilute hydrochloric acid. The cells are mounted in racks like test-tube stands, and Mr. Warren de la Rue had a collection of 14,400 such cells, with which he performed many interesting experiments at the Royal Institution.

225. *Sulphate of lead* has often been used in batteries, and a patent was taken out for using it in a series of cups of copper fixed on a copper rod. But the electromotive force is low, though fairly constant, and the cost ·1738 of a penny, subject to any residuary value. It can be used with sulphate of zinc solution, or with common salt, which, however, carries lead to the zinc plate, and undergoes a curious reaction, by which sodium appears to react upon part of the lead sulphate and generate a sulphide, which ultimately gives off sulphuretted hydrogen.

226. The next great class of generators consists of those in which oxygen or chlorine are present at the negative plate in some easily disturbed state of combination. Of these, such substances as chloride of lime, permanganate of potash, chlorate of potash, &c., have been used, but considerations of economy and convenience render nitric and chromic acids the most useful, and but for the fumes given off, which are injurious to health and surrounding substances, nitric acid would be far the best.

Nitric acid batteries are known as *Grove's* and as *Bunsen's*. Platinum is used in the Grove and carbon in the Bunsen. Form and construction are greatly varied.

227. *Nitric Acid.*—This is a solution of the true acid HNO_3 and varies greatly in strength. The following table shows the value of the most important strengths:—

STRENGTH OF NITRIC ACID.

	Specific Gravity.	Percentage HNO_3.	Equivalents or atoms per lb.	Atoms in 1000 liquid grains.
1	1·5210	100·	111·11	21·4
2	1·4518	77·777	86·42	17·90
3	1·4200	70·000	77·78	15·78
4	1·4000	66·	73·	14·49
5	1·3945	64·156	71·28	14·19
6	1·3732	60·437	67·15	13·17
7	1·2462	39·063	43·46	7·70
8	1·2402	38·121	42·36	7·51

1, *is the theoretical acid, formerly* called the 1st hydrate.

2, is $2\,HNO + 2\,H_2O$, formerly called the 2nd hydrate.

3, is $2\,HNO_3 + 3\,H_2O$. This distils unchanged at 248° Fahr., and is the strength to which boiling brings both stronger and weaker acids.

4, is an ordinary commercial strength.

6, is double aquafortis.

8, is single aquafortis.

An impure fuming acid is obtainable which cannot be valued by sp. gr., as it contains sulphuric acid and other substances, but serves for battery use. The best test for this purpose is a small Grove's cell, into which a measured quantity can be placed, so that the current it generates on a known galvanometer, and the time it will maintain it, can be observed.

228. *The reaction* which occurs is very complicated, and varies at different stages of the action. HNO_3 may lose one atom of oxygen, becoming HNO_2 nitrous acid, under two units of action which provide H_2 to form H_2O water: but one atom of hydrogen is equally able to take up one of oxygen together with the hydrogen of the acid; thus $HNO_3 + H$ becomes $H_2O + NO_2$, or, the same reaction taking place with the residue (nitrous acid) of the first case, $HNO_2 + H$ becomes $H_2 + NO$. Part of the acid is even totally deöxidized and converted into ammonia which unites with the acid, and may then be reduced to nitrite. In each of these cases the work done electrically by one atom of acid would be different; and for this reason the electromotive force falls off as the action proceeds. When cells are used for producing large currents, the reaction which occurs is confined to the giving up of one equivalent of oxygen to one of hydrogen; this reaction, which must be considered the normal one to which the E M F of 1·8 volt corresponds, continues as long as the strength of the acid is over sp. gr. 1·26, but from that point the E M F lowers, and on the other hand more economical reactions take place. It is evident, then, that the action ought to be considered from these distinct points of view.

229. When the battery is working for great force and current, the acid should not be reduced below sp. gr. 1·246, line 7 of the table, and, therefore, the working power of the acid is really $73 - 43 = 30$ units, leaving nearly two-thirds as much behind unused, besides whatever oxygen might be utilised beyond the first equivalent.

This acid is, therefore, available for further use, for purposes in which so great E M F and such steady constancy are not necessary: it might then be reduced to sp. gr. 1·16, at which strength it would still retain about 23 per cent. of acid; but the reactions would have given 3 equivalents of oxygen in place of

1, and therefore, the work of the pound of acid would be 73 − 23 = 50 × 3 = 150 units.

Besides the consumption of material needed for the current, there is a waste by endosmotic actions of from 6 to 10 per cent.

230. AQUA REGIA is used, with hydrochloric acid in the zinc cell, so as to make chlorine the active agent. I believe its introduction was due to M. d'Arsonval, as the result of a series of valuable experiments on the working of batteries; but, of course, it has long been known that chlorine and the various similar substances which will unite with nascent hydrogen are available in the battery. M. d'Arsonval recommends an *aqua regia* composed of equal volumes of nitric acid sp. gr. 1·33 and hydrochloric acid with a volume of water equal to the acids. The object of the dilution is to prevent the forming of nitrous fumes, but it is obvious that the E M F must be lower. There is also an advantage in using water containing 1 in 20 of its bulk of H_2SO_4 instead of simple water.

231. UPWARD'S CHLORINE BATTERY.—This, when introduced in 1886, by Messrs. Woodhouse and Rawson, promised to be valuable. Its E M F is constant at volt 2·1, and there is very little waste of zinc. The chlorine, generated as needed, goes to the carbon plate, and taking up the hydrogen forms hydrochloric acid needed to act on the zinc. The practical difficulties of dealing with chlorine probably proved too great, but there is certainly an opening here for workers.

232. CHROMIC ACID CELLS.—The acid itself is now obtainable so cheaply that it will supersede the various salts hitherto employed, and which act through the chromic acid they contain; but it may be convenient to commence with the more familiar forms.

Bichromate of potash is not a true twofold acid salt like bisulphate of potash, but consists of one atom of chromate of potash and one of chromic anhydride, K_2CrO_4,CrO_3. Its formula is generally written as $K_2O,2CrO_3$, or $K_2Cr_2O_7$, making its atomic weight on the new notation 295·2.

It is commonly supposed that the effect of the addition of sulphuric acid is to convert the potassium salt into chromic acid and sulphate of potash. But be the preliminary action what it may, the action of the battery is to convert the salt into chrome alum. The usual modern formulæ disguise this action, which is quite intelligible when we regard an alum as a combination of a sesqui-sulphate $M_2^{iv}\,3SO_4$ with a proto-sulphate M'_2SO_4 crystallizing *with 24 atoms of* water. The tetratomic methl, *uniting two atoms,* so as to have a valency of 6 being either aluminium, iron, chromium, &c., while the monatomic base is usually potassium or ammonium.

233. The action can be stated as

$$\left.\begin{array}{lclccc}
\left\{\begin{matrix}K_2CrO_4\\ CrO_3\end{matrix}\right\} & +\,4H_2SO_4 & = & \left\{\begin{matrix}K_2SO_4\\ Cr_2 3SO_4\end{matrix}\right\} & +\,4H_2O & +\,3O \\
295 & 392 & & 567 & 72 & 48 \\
3Zn & +\,3H_2SO_4 & = & 3ZnSO_4 & & +\,6H \\
195 & 294 & & 483 & & 6
\end{array}\right\}3H_2O.$$

That is to say, 1 atom of bichromate of potash with 4 of sulphuric acid gives oxygen equivalent to the hydrogen derived from 3 atoms of zinc acting on 3 of sulphuric acid. This is equal to 6 units of current, and makes the electric equivalent of the potash salt under these conditions about 50 grains, which quantity requires 66 by weight, or 38 by measure, of sulphuric acid to effect its own decomposition. If the acid to act on the zinc is to be provided in the same solution, an additional equivalent is needed, making the quantity for each unit of work 115 grains by weight, or 66 by measure.

234. Owing to the insolubility of the salt, the solution is weak, a pint being only about 25 units, therefore a large porous cell must be used, unless the zinc is placed within. The usual directions for preparing the solution are to dissolve 3 oz. of the salt in a pint of water by aid of heat; and when cool add one-twelfth its bulk, or 2 oz. of sulphuric acid; but this is erroneous: it only supplies the first 4 equivalents of acid, and though given for single-cell bichromates, is only suitable for a double-cell in which acid is used besides to dissolve the zinc. In order to utilize the salt completely, a nearly equal quantity of acid should be added when the action becomes sluggish; if added at first it causes too great local action, and this is always very great.

The electromotive force falls rapidly, and the resistance increases with this solution as the chromic alum forms; this also frequently crystallizes in the solution and upon the carbon, so that it is bad economy to work it to exhaustion. The change of colour to green indicates the completion of the reaction.

235. *Hydrochloric acid* used instead of sulphuric avoids many of these defects. The solution can be prepared with equal volumes of the cold saturated solution of bichromate of potash and of hydrochloric acid. As the reaction produces a neutral chloride of chromium instead of sesqui-sulphate, the equivalent is 37·5 instead of 50, so that 1 molecule (295) of the salt, *with 6 atoms* HCl is equal to the production of 8 units of *current, requiring* a further 8 atoms (14 in all) of acid to

dissolve the four atoms or 8 equivalents of zinc. No crystals form in this solution.

236. *Voisin's red salt* is convenient for amateurs who wish to avoid the trouble of acids; it contains the acid in the proportion of the formula § 233. It gives the same E M F as the ordinary solution, and is rather more constant, but produces a greater resistance. It should be dissolved 20 to 25 parts to the 100 of water: that is, 4 oz. to 5 oz. in a pint. It consists of

$$\underset{140}{Na_2SO_4} + \underset{686}{7\,H_2SO_4} + \underset{295}{K_2Cr_2O_7}$$

which is probably changed by the action into

$$2\,NaHSO_4 + 2\,KHSO_4 + 2\,CrO_3 2SO_3 + 7 \text{ water.}$$

It is made by dissolving the sulphate of soda in the heated acid, and gradually stirring in the bichromate; it is then poured into moulds, and after cooling, removed and broken up.

237. *Bichromate of soda* introduced a few years ago, has many advantages over the potash salt. Its reactions are the same, but the soda alum (if formed) does not crystallize. Its great superiority, however, is its much greater solubility. It dissolves in an equal weight of water, and the solution takes half its bulk of sulphuric acid. As this solution is at least 4 times as concentrated as that of the potash salt § 234, it not only works longer, but it does not lower its E M F. This will be understood by reference to § 214; the same remark applies to chromic acid solution; in fact, there is a great resemblance in the working of these two oxidants. The pure acid is however preferable if any attempt is made to utilize the products of working, which may be done by throwing down the zinc and sesquioxide of chromium to produce paints; in this case the soda introduces trouble as it is very difficult to get rid of.

238. *Chromic acid* (more correctly chromic anhydride) is now produced by Sullivan's process at a cost per lb. not greatly in excess of that of the bichromate of potash: the acid as sold for battery uses, contains about 65 per cent. Cr_2O_3, which is about the same as the potash salt, but the other constituent is H_2SO_4 instead of potash, and is useful instead of noxious.

The solution is made with 1 lb. in 1 pint of water, and 7 fluid ounces of sulphuric acid, and the resistance of this is about the same as that of nitric acid; its working strength or concentration is five or six times that of the potash solution, with the resulting *steadiness of E M F* and currents mentioned § 237.

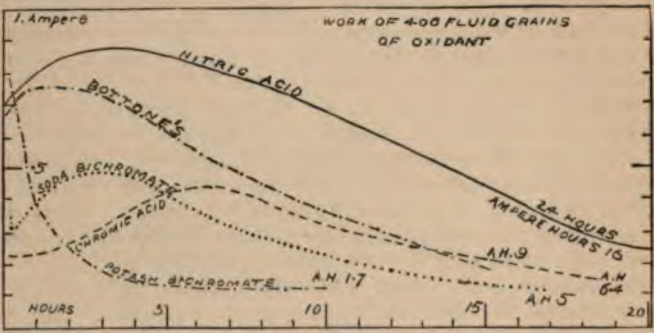
The action may be compared with that of the potash salt § 233.

$$\left.\begin{array}{lllll} 2CrO_3 + 3H_2SO_4 & = & Cr_2 3SO_4 & + 3H_2O & + 3O \\ 201 \quad\quad 294 & & 393 & \quad 54 & \quad 48 \\ 3Zn + 3H_2SO_4 & = & 3ZnSO_4 & & + 6H \\ 195 \quad\quad 294 & & 483 & & \quad 6 \end{array}\right\} 3H_2O.$$

The actual weight needed of the commercial article would be about 300 in place of 207, but it would supply 100 of the H_2SO_4, so that these are the figures to be compared with the 295, or practically 300, of bichromate of potash, when considering the relative costs.

239. In Fig. 36*a* I give the results of a comparison of these reagents: I used a porous cell containing with the carbon plate 400 grains of the liquid to be tested; the zinc plates in acid 1–10; the conditions alike in each case, and the external circuit, consisting of a tangent galvanometer and a copper voltameter to measure the total work done by each reagent. The current is shown in the curves, which convey more complete information than pages of description.

FIG. 36*a*.



The horizontal line is time of working in hours, and the vertical line is currents in tenths of amperes, and the curves of current bring out the relative values very clearly. The rapid fall of power in the bichromate of potash is very evident. The chromic acid and bichromate of soda run each other very closely, but the acid does most work. But the nitric acid is vastly *superior to all the others.*

The work done in ampere-hours was

Nitric acid	16·
Soda bichromate	5·
Potash bichromate	1·7
Chromic acid	6·4
Bottoné's solution	9·

240. It may be useful to give the relative resistances of the various liquids, which I measured in the instrument described in the chapter on Resistance.

		Sp. Gr.	Resist.
1.	Sulphuric acid 1 vol., water 12	1·085	60
2.	Sulphate of copper, sat. sol.	1·172	656
3.	Same, + ¼ vol. of line 1	1·155	195·5
4.	Potash bichromate, sat. sol.	1·028	698
5.	Same, + $\frac{1}{12}$ vol. sulphuric acid	1·130	70
6.	Soda bichromate, sat. sol.	1·422	220
7.	§ 237. Same, + ½ vol. sulphuric acid	1·552	80·4
8.	Chromic acid 1000, water 1250	1·353	48·7
9.	§ 238. Same, + sulphuric acid	1·454	57·9
10.	Nitric acid	1·375	56·9

These resistances, however, vary soon after some action has gone on in the cell; the nitric acid, in particular, lowers its resistance greatly as it becomes saturated with the nitrous gases generated by the action.

241. *Bottoné's solution* consists of chromic acid 6 parts, water 20, chlorate of potash ⅓ part, and sulphuric acid 3½ parts by weight. As will be seen in Fig. 36*a*, the chlorate of potash considerably increases the EMF and the working capacity. I think this is due partly to the giving off of a little gas: this however has its objections, as in the case of nitric acid.

242. *Nitric acid with bichromate of potash* has been highly spoken of by some writers as giving a constant current and no fumes. It is true that the constancy of the current is improved, but after a little time the fumes are given off; the reaction is simply the reoxidation by the bichromate of the reduced nitric acid. The solution recommended is a saturated solution of bichromate in nitric acid, with one-third volume of sulphuric acid added, and just enough water to dissolve any chromic acid precipitated.

But Mr. J. W. Swan, who is a good authority, says that the addition to *chromic acid* of one-third its weight of nitric acid gives a great improvement in constancy without producing fumes. This would be due to the giving off gas, which remains in solution and is reoxidized by the chromic acid. He also states the somewhat curious fact that this solution, while working well with a carbon plate, fails with a platinum one.

243. *Alkaline nitrates* have been proposed in place of nitric acid; in fact, they are the basis of several of the later patented batteries of which one hears very wonderful accounts and highly successful installations, but which soon descend to an early grave, especially if a company is formed to work them. When a solution of these nitrates is mixed with sulphuric acid, a reaction takes place by which the base is divided between the two acids in ratios depending on the relative proportions present; hence results a solution containing a proportion of free nitric acid which acts in the usual manner, while the remaining nitric acid is only set free as the action of the battery proceeds. Nitrate of soda is best; it is cheaper by the pound, its equivalent is lower, and therefore the pound does more work, and it is very much more soluble, and therefore a much more active solution is obtained. It is not, however, generally known that water, when fully saturated with one of these salts, will still dissolve nearly as much of the other as though it were pure water, and thus the strongest solution is made by dissolving both the salts together. With nitrate of soda at 2*d.* per lb., the cost of the atom of nitric acid obtained from it in the cell is ·0456, against ·1096 of the acid. But such solutions have a vastly greater resistance than the simple acids, and are not fit for generating energetic currents. They also give a much lower E M F.

244. *Any substance containing oxygen or chlorine in unstable combination* may, in fact, be used at the negative plate, and inventors and patentees are fond of giving their name to and claiming the use of these (see § 202). Thus, solutions of chlorate or permanganate of potash, chloride of lime, and many other substances are available, and may be useful under some circumstances, as to which see also §§ 275–6.

245. *Battery construction*—It is waste of time to describe mere variations of shape and arrangement: I prefer to explain the principles which can be adapted to any case. Thus, we have two names for nitric acid cells; the *Grove* has platinum for its negative plate, while carbon is used in the Bunsen, and we are practically limited to these two substances.

Iron, whether wrought or cast, though often praised, and used long ago in the Callan or Maynooth batteries, is a mere annoyance: it assumes what has been called the *passive state*, in which strong nitric acid has no action on it. This state consists in the formation of a film of iron oxide, insoluble in the strong acid. When the acid weakens the protection fails, the iron is acted on, and the acid boils over. Its E M F is much lower than that of carbon.

Aluminium has been suggested, as not acted on by nitric acid; a doubtful statement: its E M F is lower than that of carbon, and this means waste of acid and zinc.

246. PLATINUM.—This is by far the best, except for its first cost, against which must be set the fact that after prolonged use it has two-thirds its first value, and is not diminished in quantity. As a rule platinum is used too thin, which has the double defect of liability to injury and of producing resistance, as the metal is low in conductivity.

A modification of the old Sheffield plating might prove valuable: a slab of copper tinned and covered with platinum sheet soldered to the copper and then rolled down, would give a plate with the conductivity of copper and yet the E M F and endurance of platinum. If deposited metal were not porous an excellent plate might be produced from it in this manner.

Surface of plate is of great importance, and it is well to corrugate the platinum vertically, both to increase the surface and to give rigidity to the metal; and it is also an improvement to deposit very slowly a coating of crystalline platinum.

247. CARBON.—This is, electrically, as good as platinum; in fact, it has a slightly higher E M F. The objections to it are its brittleness, its tendency to soak up the liquid, the difficulty of making a good connection to it, and the risk of eating away the metal contacts and forming some non-conducing substance at the junction. Carbon has several allotropic forms, as the diamond, charcoal, and graphite or plumbago. The last is used for batteries in its form of gas-carbon. This is *not coke;* coke is the solid residue left after distilling coal; the graphite comes from the *gas*, the rich hydrocarbons of which are decomposed by contact with the heated retort, on which they form a shell; in the gas-works it is called "scurfing." The densest and hardest is the best for electrical use; it should be almost non-absorbent, and ring like a metal when struck, and have a clear grey colour, not black. The best mode of cutting carbon is that employed by stone-cutters, by means of a piece of iron, sharp silver sand, and water; important elements of the process are time and labour, for the material, if good, is very hard to work, and this is the chief element in the cost.

248. ARTIFICIAL CARBONS.—Plates or blocks may be made of powdered graphite mixed with coal-tar or strong rice paste, dried, packed in powdered carbon in a closed vessel and heated to clear *red for some time.* When cool they should be soaked

in strong syrup, again dried, and treated as before; this process must be repeated until the carbon is perfectly dense and strong. In this way are made cylindrical vessels, left somewhat porous to hold the acid and act the twofold part of porous jar and negative plate; many of the plates and blocks in batteries of French make are thus made, and work fairly well, but under some chemical reagents they break up.

A new quality of carbon made in this manner is now at our disposal in the thin rods (true carbon wires) made up for the electric arc lights, which are also useful for resistances: they are valuable for batteries because of their density and freedom from cracks, as also for the ease with which they can be arranged to give large surface in small space. Defective rods may be had cheap; the tops should be coppered, tinned, and soldered to a strip of copper; or they may be roughened, and a head of lead cast upon a number of them. They should then be carefully paraffined to resist liquids.

249. CONNECTING CARBONS.—This is the great difficulty; it is commonly done by fixing a clamp on the end, when a piece of platinum ought to be interposed between the two surfaces. A better plan is to deposit copper on the upper part, and then solder the connection to it, as this gives continuous circuit; the copper takes on it just as it would on a metal. There is one drawback to this, the same in fact which requires the platinum interposed in the first plan; the acid both creeps up the surface and soaks into the substance, and then acts on the copper and destroys the connection. The following plan, which I devised many years ago, is a protection against this, *provided it be thoroughly carried out*:—

Heat the end of the carbon, and touch the part just beyond where the copper is to extend to (which should be about half an inch from the end) with a piece of paraffin, taking care it does not run up the part to be deposited on; should it do so, it may, however, be driven off by strong heat; when cold, cut a few scores in the surface to give a hold to the copper, and drill a hole through, in which fix firmly a copper wire projecting on each side; now with a warm iron spread a good film of paraffin from the intended coppering to the part to be immersed in the liquid when working. Connect a wire to the carbon by a screw clamp, and insert in a copper solution, arranging at first for a quick deposit to prevent entrance of moisture into the pores of the carbon. When a good deposit is made, drill a few holes right through copper and carbon, soak in water to remove any absorbed copper salt, and dry it thoroughly. Now tin the part to which the binding-screw or connecting-wire is to be soldered, and stand the carbon with its coppered part in a vessel containing a little melted paraffin till its upper part is saturated, the holes being intended to insure this. When the connection is soldered a coating of paraffin may be spread over the copper. No cement is of any use for this purpose, paraffin alone resists powerful oxidants, such as nitric acid, and caustic alkalies.

250. *Surface of carbon* is of even more importance than with platinum. There are many uses for batteries which give a powerful current for a limited time: for these a cell which would hold just sufficient nitric acid for the occasion, would be valuable; for this we need a porous cell which will only just hold this quantity, and which shall yet have in it a plate surface capable of generating the required current. Again, the chromic acid cells fail very rapidly, owing to polarisation, and a large negative surface is the best remedy. There are two modes of attaining these objects.

Granulated carbon may be packed in the cell around one or two plates or rods serving as conductors, in the same manner as in the manganese cells: the connection to the separate particles is, however, imperfect at best. This plan is only available with acids, either as a Smee, or with nitric acid; it is not suitable to chromic salts, as they tend to form deposits on the surfaces, which break the connection.

Carbon rods, § 248, may be packed into the cell with enough space for the liquid, their tops being all connected.

251. INCLOSED CELLS.—These are very convenient, and either form of carbon can be used in them. The space within or around a porous cell can be used, and of course the outer space gives most room. I have found it convenient to use a porous cell perforated with holes fixed into the containing vessel, using a second porous cell for the zinc, which is inserted in the other only when required for use. The oxidant can then be left in the containing vessel for further use, and the opening closed with a stopper. I thought I had arrived at perfection, and done away with the nuisance of charging and emptying nitric acid cells, but there is an *if* in the way; the plan would be perfect *if* we could find a perfect means of inclosing the top: as it is, I can only describe the best results I have attained.

Arrange the carbon in the cell, and also a glass tube for supplying the liquid, reaching nearly to the bottom: shake in dry sand, if rods are used, or salt, if with granulated carbon, filling to within an inch of the top. On this place a layer of cardboard boiled in paraffin, in a hole in which is inserted a glass tube just *entering the sand*. Now, *after warming the tops* *of the cells*, pour in melted paraffin just about to set. I have run in plaster of Paris, and after drying have turned the cell upside down in melted paraffin, allowing it to soak into the plaster and form a stratum the thickness of which can be controlled by the depth to which the vent-pipe enters the cell; but the paraffin breaks up into minute fissures, and ultimately the plaster disintegrates. After all is set, the sand can be shaken out through the vent-pipe, or the salt dissolved.

It is possible that the sulphide called Spence's metal might answer as a cement to close such cells.

252. CIRCULATION OF LIQUIDS.—The chromic acid cells always lose power very quickly, the solution in contact with the negative surface being exhausted: therefore the possible rate of current is limited by the capacity for renewal of this solution by diffusion, which is a slow process. This means that there is for every kind of action a definite ratio between current and surface. This is why enlarging the surface makes E M F more constant, although *surface per se is no function of E M F.* Consequently, any means of bringing active solution to the negative plate maintains the E M F. In nitric acid this is effected by the generation of gas. Circulation in the liquid, however produced, has the same effect.

253. *Heat* applied to the bottom of a cell has this effect: probably the heat adds to the E M F as in § 212, but at all events it keeps it nearly constant by bringing fresh liquid to the plate. I have obtained a constant current from a bichromate cell, close up to exhaustion, by means of a small gas jet under it. The heat also lowers the internal resistance, and so compensates for the lowering of E M F due to the chemical change of the solution.

254. *Chutaux* and others have arranged the cells of a battery, so as to permit the liquid to pass through them slowly from a reservoir above to one below: and they exchange the receivers at intervals, so as to pass the liquid several times through the battery.

255. *The enclosed cells*, § 251, could be readily used in a similar manner. If the outlet or vent-pipes (provided for emptying the cells and allowing gases to escape) were of proper length, and bent over so as to enter the inlet or feeding pipe, the liquid would flow from one cell to another with very small difference of level; and if connected together by caoutchouc tubing they might be at one level, and the liquid forced through them at any desired rate by the elevation of the reservoir.

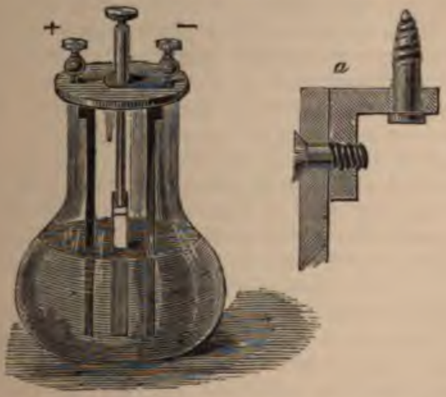
256. *Rotating carbon plates* have been used to attain the same result. The carbons are in the form of discs mounted on an axis,

with only the lower half in the liquid, so that the motion of the axis brings new carbon surface, carrying also a film of air, and also stirs the liquid.

257. *Pumping air* into the liquid is another mode of causing circulation, and though it does not add to the E M F it prolongs the action of the liquid by bringing oxygen to the plate.

258. Bichromate Single Cell.—This consists of two plates of carbon, with one of zinc between them, fitted so that it can be raised out of the liquid. Of late many shops have small bichromate cells without this fitting; I would warn readers against using such cells, which are most extravagant and unsatisfactory. Used for the purposes to which it is suited, the bichromate cell is one of the most useful; it furnishes a most powerful current for a very short time: it is therefore admirably adapted for short experiments with induction coils, as it gives a greater force than nitric acid, and has no unpleasant fumes, while it can be set aside for weeks and be ready for action at any instant. But for long-sustained action it is useless. When the force fails, merely raising and lowering the zinc restores it for reasons explained § 252. Fig. 36*b* shows the usual construction.

Fig. 36*b*.



The vessel is a glass bottle, enlarged into a globe below, to hold a larger quantity of liquid; but any form of vessel will answer. The essential part is the top which carries the plate; this is best made of ebonite, but hard baked wood saturated with paraffin will *do; in the centre of* this is screwed a projecting brass tube split at the top to grip the rod carrying the zinc which slides in it: the foot of this tube also passes through a plate of brass extending on one side of the cover to the negative binding-screw. This sliding part is often troublesome, as the surfaces tarnish and make bad contact; they should be well gilt to avoid this, and some attach an open spiral of wire to the lower part of the rod and to the tube, so as to make a fixed metallic circuit independent of the sliding one; others attach the binding-screw to the top of the sliding rod. It is desirable to form a screw-thread on the top of the tube, and fit to it a nut, by tightening which contact is improved, and the zinc firmly held up when not in action; a square tube and rod are better than round ones, as they keep the zinc always parallel with the carbons. The zinc is commonly fixed to the rod by means of a screw on the end, but it is far better to solder them together. I was once greatly troubled with an irregular battery, which would not keep to its work, though I pulled it to pieces and set everything right, as it appeared, and after great trouble traced the whole fault to this point: acid had found its way into the thread of the screw and entirely destroyed the connection. The carbons are secured to the cover by means of two angle pieces or brackets of brass or iron, as shown (*a*, Fig 36*b*), and these brackets are connected to the + binding-screw. The connection is thus one of simple contact, and with a porous carbon it is common for acid to find its way up between the surfaces and destroy the contact. This may be entirely remedied by the plan described in § 249; the upper part of the carbon being coppered the bracket may be soldered to it, and perfect connection insured, and protected by a covering of paraffin.

It is impossible to estimate the cost of working this cell, because the local action in it is so great; and this being nearly constant while the zinc is immersed, or when frequently removed, its proportion to the work actually done will be less as this is greater, greatest that is when there is great resistance.

259. A very convenient form of this cell is a battery and commutator combined, for bells and other appliances requiring a momentary current; the zinc and its rod is supported by a spring, spiral or otherwise, and is pressed into the liquid when the current is required; on relieving the pressure the zinc leaves the liquid, and cuts off the current. The same form of cell is also used in apparatus for obtaining light, and for lighting gas. The zinc plate should be parallel to the surface of the liquid, so that a small motion will immerse it.

260. The suitable solution is given § 234. Trouvé's solution is *cold-water 36, bichromate* of potash 3, add slowly 15 of sulphuric acid. Of course, any of the chromic acid solutions can be used in the single cell, but they ought not to be used in such strength as described for double cells, and they will require more sulphuric acid added after a time, in order to dissolve the zinc: the acid stated is employed in the reaction of the salt itself, to dissolve the chromic oxides formed.

261. Slater's Iron Cell.—In almost all the forms of battery iron may be used in place of zinc for the dissolving metal, but owing to its lower electromotive force, and other practical reasons, it is seldom employed; Mr. Slater introduced a cell in which iron as the negative metal is combined with nitrate of soda as the oxidant. The sulphuric acid is added to a hot solution, and sulphate of soda crystallizes out in cooling. At starting, the outer cell is charged with water, containing a little of the solution to render it conducting, and set up the action, which is then kept up by endosmose; the action is maintained by removing a portion of the inner liquid at times, and adding fresh solution, so that there is little waste.

262. Iron Perchloride.—This has been employed in batteries; its action consists in undergoing a reduction to ferrous chloride, and the object aimed at was the regeneration of this by absorbing oxygen from the air, so as to maintain an inexhaustible oxidant. It may also be regenerated by passing a stream of chlorine into the cell. It has the same drawback as the bichromate battery in rapid failure, and its force is also low: there are, however, cases in which such a combination might be useful, and it will form a single cell with iron as positive, and work to exhaustion if free acid enough is occasionally added and the excess of liquid removed.

Peroxide of iron might be employed for similar reasons, instead of and in the same way as the manganese peroxide, but it gives only just half the force of the latter.

263. Peroxide of Manganese Battery.—Various peroxides have been employed to surround the negative plate and furnish the oxygen. The peroxide of manganese was first used by De la Rive, many years ago; but the difficulties which soon present themselves to those who use it, limit its applications, though it has many good qualities, which have brought it into use, and it has been patented under the name of "Leclanché" cell. For cases requiring a large current, as in plating, or for magnets or coils, it is absolutely useless; for a small occasional current, on the other hand, as for ringing bells, household signals, &c., it is one of the most useful forms; it requires no attention beyond seeing that it does not get dry: and it remains active for a long while, when used for its proper purposes.

The peroxide of manganese is $MnO_2 = 87$; two of these molecules enter into the reaction producing Mn_2O_3 sesquioxide of manganese, and O 1 atom of oxygen; therefore 87 of it by weight yields 8 of oxygen, and 1 unit of current; but this is the pure substance, while the commercial manganese contains a large percentage of impurity, so that 100 is about the unit. As no solution occurs, the action takes place only on the surface of the particles, and a considerable portion may escape action; it is therefore impossible to fix upon any quantity as the electric unit; it may range from 100 to 200 grains or more. According to Leclanché to 100 parts of peroxide and 100 of sal-ammoniac, there are 50 parts of zinc dissolved. The peroxide is a good conductor; the resulting sesquioxide is not a conductor (and the same is the case with the corresponding lead oxides), hence the action tends to diminish; and a main object must be to spread the material over a large area of conducting surface. This is accomplished by crushing carbon into various sizes, from a pea down, and packing the larger pieces in a porous jar, in layers, so that the particles are in firm contact among themselves, and with a plate or bar of carbon which forms the main plate or conductor; the finer grains should be mixed with three times their bulk of manganese, also in fine grains and sifted in among the network of large pieces: the fine powder has to be sifted out, because it resists the penetration of the liquid. The result of this arrangement is to expose a very large surface, which compensates for the inherent slowness of the action itself, and reduces the internal resistance.

A small surface of zinc is sufficient, such as a cast rod or rolled strip suspended in the outer vessel.

264. This is the usual arrangement, but it is far better to reverse it, and put the zinc inside the porous vessel, making the battery up as described § 251 with the manganese added as above.

A very compact form has been introduced, made on this plan, called the Lacombe battery: a carbon cell contains the manganese mixture between itself and a small inner earthenware cylinder to hold the zinc: both cells being perforated to allow circulation of the liquid contained in a glass jar.

265. *Agglomerate blocks* are much used, to do away with the porous cell. One composition consists of manganese peroxide 40 parts, carbon 44, gas tar 9, sulphur 0·6, water 6·4, all strongly pressed together after mixing, and heated to 365° C. to drive off the water and tar.

266. THE EXCITANT.—Either common salt or sal-ammoniac is employed, though others will answer. It may seem unwise to

use sal-ammoniac at *6d.* per lb. if common salt at 3 lb. per penny will answer; but as a couple of ounces of the chloride of ammonium will charge a cell such as the ordinary Leclanché, and work for several months, the question of economy dwindles to a very small matter against the higher electromotive force the ammonium chloride gives over that furnished by the sodium chloride. With the latter caustic soda is generated and remains to exert a counter E M F, while with sal-ammoniac, ammonia is set free and given off. The force is greatly increased by occasionally adding a little acid to the manganese cell to neutralize the alkali.

I have found the E M F at first starting to be with—

Sal-ammoniac	1·543 volts.
Sulphate of ammonia	1·493 "
Common salt	1·285 "

Ammonium chloride forms double salts with zinc chloride, and also with hydrated zinc oxide, and the latter compound appears in the form of crystals upon the zinc and porous cells. The crystals have the formula $Zn\,O, H_2\,O, N\,H_4\,Cl$. As they obstruct the action they should be removed with warm water containing a little acid, but they do not form so readily if a half-saturated solution is used.

Another trouble is that the ammonium chloride finds its way between the carbon and the lead cap usually cast upon the carbon as a connection, and produces a film of non-conducting matter between them. They should be protected as described § 249.

The manganese may be regenerated without removal, by thoroughly washing with warm water, and then pouring in a strong solution of permanganate of potash; repeating this as long as the colour is discharged: but it is a doubtful economy.

267. For many purposes a cell constructed with crushed carbon, as described, will serve without the addition of manganese, especially if the cell is made rather high, the solution rising only half-way up it, and free access of air allowed to the carbon: but this is available for only very short demands upon its force. The E M F also is lower.

268. *Peroxide of lead* is a most powerful oxidant, and is the basis of all the secondary batteries: as it is easily regenerated it will become more valuable as the plate of ordinary batteries, when there are places at which a current can be used to regenerate an exhausted plate.

Roberts' cell is highly spoken of in American papers, and is made with red lead mixed with its equivalent of potash permanganate, *and made into a pasty* mass with H Cl: this is put into a porous cell, containing a carbon conductor: it sets into a porous conducting mass.

Lithanode is a solid form of lead peroxide, invented by Mr. D. G. Fitzgerald, and is the most practically useful form of the material. It is prepared from a pasty mass of litharge and water, caused to set by a slow chemical reaction; the insoluble plate is then transformed by the electric current into hydrated peroxide of lead, containing a little sulphate of lead. The chief difficulty is making good connection, which requires platinum foil and wire, nothing else withstanding the reactions; they are secured to the plates with ebonite screws and nuts. The E M F of lithanode with zinc in sulphuric acid is nearly the full power of zinc, and therefore exceeds 2 volts, and its work is about one ampere hour per ounce.

269. OXIDE OF COPPER.—This was introduced by Messrs. Lalande and Chaperon, and a good deal more was expected from it than has been realized; still it may be found useful. It consists of a cast-iron vessel, preferably of the form of a wide-mouthed squat bottle, on the bottom of which is placed a layer of oxide of copper, copper scales from red-hot copper being the best; the excitant is a strong solution of caustic soda or potash, which, after use, can be treated as in § 190; the zinc is suspended from the stopper. The copper oxide can be reformed by washing, drying, and roasting at red heat. The great defect of the battery is that its E M F is less than volt ·9 and falls to ·6, while working.

270. *Bennett's battery*, sometimes called the tin-pot cell, as meat tins were suggested for the outer vessel, consists of an outer iron vessel with a porous cell, and the space between packed with iron borings; in all other respects it is the same as the last described.

271. EARTH BATTERY.—A plate of zinc and one of copper, or a bag of coke, buried a little apart in moist earth, has been used under the name of an earth battery, for driving clocks. This is its only use, and as it has a low force and high resistance, all that can be said in its favour is that, once mounted, it is out of the way and requires no attention; but any ordinary small cell will do as much work. It is not possible to have several in series, but the action can be increased by placing the zinc plate under a stable or in other position where saline liquids can penetrate. Some have constructed an earth battery by using the lead water-pipe as one plate and the iron gas-mains as the other; but this means injury to the latter, and that injury is likely to occur at the nearest possible point to the *user.*

272. *Water batteries* of simple construction have been described, which may be found useful for many experimental purposes, such as with electrometers, or as variable E M F's where a high voltage and infinitesimal current is required. Professor Rowland first described a simple form which I have somewhat modified. A strip of thin copper, 2½ inches wide, and a similar one of zinc, 2 inches wide, are laid together and solder run along the edge at which the copper overlaps. The strip is then cut into pieces ¼ inch wide, each forming a copper zinc pair. A piece of dry wood, a foot square, has saw cuts made across one face of it ⅜ inch apart, and is then baked and paraffined. (Professor Rowland used a sheet of glass and shellac.) The projecting copper ends are slightly warmed and pressed into the saw cuts in regular order to form even rows, and melted paraffin run over the wood to make all strong. By aid of strips of wood or metal, the pairs are now opened out, so as nearly to touch the adjoining plates, the ends of the rows being separate zinc and copper plates connected together by the top edges. The distances of the plates are so arranged that when dipped into water a few drops will be retained, which will take some time to evaporate, and can be renewed by dipping afresh. Thick porous paper may be inserted if preferred, thread being wound round the plates to hold it in place.

A more complete battery can be made in the same way, but with rows of test tubes placed over the pairs; these are then to be put into a box and some cement, preferably paraffin, run in to hold them in place.

By taking wires through the top at intervals varying numbers of cells may be used, so as to control the E M F employed.

273. *Gas batteries* have received some attention of late: they offer the tempting prospect of deriving electric energy direct from the combustion of fuel, and so dispensing with the steam engine and dynamo. The first was devised by Grove, the inventor of the nitric acid battery, and is simply the voltameter reversed; that is to say two plates of platinum in gas receivers, dipping into a vessel containing dilute acid: oxygen and hydrogen supplied, combine and give up their energy as electric current. As yet no form has been devised which can be said to have a practical value. But that may come yet. Like the thermo-pile, they are good theoretically, but in practice they only utilize a small portion of the energy supplied to them.

274. *Dry batteries*, so called, have excited much interest of late, especially among inventors, and no doubt they have uses; but it seems obvious that they *must* be, on the whole, less effective

than those in which the liquid is free to move. They are usually Leclanché cells in which the excitant is rendered semi-solid.

Gasner's was the first to come into use, and gives satisfaction. Recent tests carried out at Munich indicate that Hellesen's is most effective.

One mixture is water 1 pint with enough plaster of paris to make a cream which does not set; with this is mixed 1 oz. each of oxide of zinc, ammonium chloride, and zinc chloride.

Others use mineral jellies derived from silicate of soda; or a saturated solution of magnesium chloride to which sufficient magnesia is added to form a pasty cream. All of them polarize very quickly, but recover their E M F after a rest: in fact they suit work which only calls for occasional short currents, where there is motion, or difficulty in giving proper attention.

275. There are many other forms of the galvanic cell; many useless; most mere modifications or forms of those described. Others have great scientific interest, but do not come within the objects of the present work. I have intentionally omitted all mention of patent batteries, and secret oxidants, as of little interest to readers. As before mentioned, batteries can be made out of any chemical reaction in conducting materials, and especially from any substances which readily give off oxygen or chlorine. They can be made also by arrangements which facilitate the absorption of atmospheric oxygen, and of these, one of the most interesting is that proposed by Messrs. Gladstone and Tribe, who have made so much use of the electrolytic action upon substances of a copper-zinc couple, formed by zinc on which pulverulent copper is precipitated from the sulphate. When silver and copper are connected in a solution of copper nitrate well aerated, the copper dissolves and cupreous oxide is deposited on the silver; a similar action occurs in a solution of zinc chloride with zinc and copper. The negative metal is arranged as a tray near the surface, perforated in many places, and containing also crumpled masses of the metal in foil rising above the liquid to facilitate absorption of oxygen. Such means of absorbing oxygen from the air may be applied to many reactions, and offer good promise of utility, especially on a large scale.

276. Batteries are being largely superseded by dynamo-machines, as a matter of economy. The principles indicated in this chapter may show manufacturers and others that in many cases economy will tend to the opposite process. As all chemical *reactions* which occur spontaneously liberate energy, which is *usually wasted in practice*, but might be converted into electrical

work, it is evident that this "waste product" may be utilized. The production of metallic paints, solutions for dyeing purposes, and many other chemical products, might well be combined with the production of electric currents to bring about other reactions which now necessitate the supply of external energy, usually effected by means of heat. But this is true only where there is immediate use for both products: many patents have been taken out for batteries giving useful products: they all fail, because they do not pay the cost of collection; and also a product may be valuable when it has to be made for a purpose, and become worthless when produced on a larger scale. These are the pitfalls of inventors.

277. Arrangement of Batteries.—The laws which govern the mode of arrangement of a number of cells, in order to effect most work, will be found in the chapters on Current and Electromotive Force.

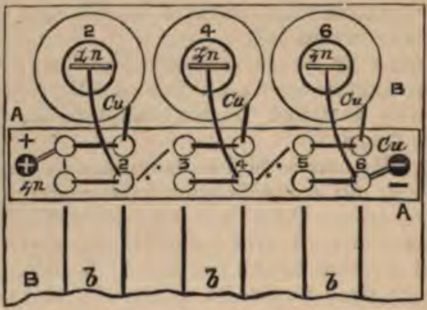
In joining cells, care should be taken not to waste energy in the connections; all contacts should be as large as possible, and perfectly clean. This is often neglected in mounting batteries, particularly in Grove's cells, where the platinum is bent over and screwed to the next zinc; in all such cases the metal should be fixed to a thick plate of brass, so as to screw firmly to the zinc.

The connecting wires should be of good size, and should be wound in a spiral in order to give some elasticity. Care should be taken that the troughs, boards, &c., are quite dry, and that there has been no leakage or creeping of liquids from the cells, which causes short circuits and great loss of power. To avoid this, the jars should not stand directly upon a board; but a good plan is to place two strips of varnished glass edgeways along the troughs or stands, for the cells to be placed on.

278. A plan I have found very convenient is shown Fig. 36c. B is a wooden base across which are secured strips *b b* of glass, A is a bar of wood raised to the suitable height, in which are sunk holes, marked 1–6, each pair intended for the connections of one cell, while one row is for the whole of the zincs, and the other for the positive poles of the cells; each row is permanently connected to a binding-screw + and − by wires under the wood let into the last hole of the row: the holes are to serve as mercury cups, and should be $\frac{3}{4}$ inch deep: pieces of copper wire, bent over at each end, connect the cups as desired; they are shown connected two cells in multiple arc, and in series of three. The cells are placed 3 on each side of the bar A. The outer cells *Cu* (as Daniells) have wires which connect them to their proper cups, as have the zincs. When the battery is out

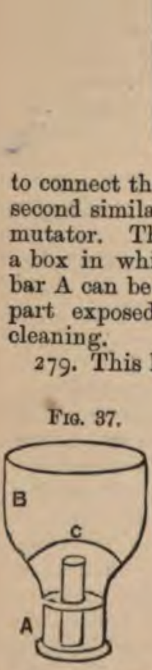
of use, the zincs can be lifted out and placed in a jar of water, with corks on the ends of their wires; the porous cells can be also removed and stood in a vessel containing the same liquid as themselves; the copper cells remain in their place, with covers on, and the whole is again mounted in a minute when required. It is evident that, if the battery is to be kept somewhere inconvenient of access during experiments, the bar A may serve only to connect the cells, and wires can be led from the cups to a second similar bar elsewhere which will serve only as the commutator. This plan is also convenient when B is the bottom of a box in which the whole battery inclosed; then the second bar A can be attached to the outside of this box and be the only part exposed. A should be removable for convenience of cleaning.

FIG. 36c.



279. This latter mode also is suitable with the closed nitric acid cells described § 251; these should have a rather long upright vent-tube rising straight up from the cell; a tray can then be placed over the whole of the battery (or one to each cell) with holes in the bottom for the tubes to pass through the tray containing lime in lumps or powder to absorb the fumes.

FIG. 37.



Another mode of effecting this absorption of fumes is shown Fig. 37. B is a bottle cut off (or a closed flask may be used) with its neck fitted with a cork carrying a tube to be placed over the vent-tube of the cell; a tray *of perforated lead* C in the bottle supports lumps of lime or chalk. *All the wood should* be baked, and then boiled in paraffin of which a good coat should remain on the surfaces, and the copper wires should be well protected with varnish except at the ends dipping in the mercury, which should be amalgamated and have corks stuck on them when out of use. It should be remembered that when a strong current passes through a porous material, it carries the liquid with it from the zinc cell, § 204; space must therefore be allowed in the carbon cell, or otherwise the liquid will be apt to overflow.

280. *Economy in working* consists largely in using up the materials completely. This often involves a loss of E M F, and the necessity for waste, which can be avoided if a few extra cells are provided, and the battery divided into sets, of say 3 or 4 cells. If the sets are changed in rotation, one set being cut out of the action, for the necessary time, those of weaker force can be still left in action, as long as is really worth while, because § 173, p. 107, cells of varying E M F can be worked *in series.* This applies especially to such cases as § 229.

281. WORK AND CONSTANCY OF CELLS.—Table IV. gives a series of experiments on cells, all in like conditions; with plates 2 × 1 inches, set 1 inch apart, and with no external resistance, except that of a tangent galvanometer. The currents are given in chemics, and therefore are proportional. In the cells with porous division, it will be seen the current rises at first as the liquids soak in; in these cells, also, the current is reduced by the resistance of this division as compared with the single liquid cells. See also § 239 and Fig. 36*a*.

TABLE IV.—WORK AND CONSTANCY OF CELLS.

	Minutes.				Hours.	
	1.	5.	15.	30.	1.	2.
Copper-zinc	5·2	4·2	3·8	3·5	3·2	3·
Iron	2·9	2·	1·7			
Lead	4·9	0·5				
Platinised silver	17·7	13·7	11·	9·	7·3	6·4
Daniell's	6·8	6·9	7·2	..	7·1	7·
Bunsen's nitric acid	12·	..	..	13·	13·1	12·
Slater's	7·8	7·3	7·	6·8	5·9	4·2
Bichromate	7·3	7·8	7·3	7·	4·	2·1
„ Single cell	12·	10·6	9·4	8·4	3·8	1·1

TABLE V.—SUBSTANCES USED IN ELECTRIC WORKING.

I. Name.	II. Atomic Weight.	III. Valency.	IV. Commercial Equivalent.	V. Equivalents per lb.	VI. Price per lb.		VII. Cost per unit.
			grains.		s.	d.	d.
1. Acid hydrochloric	36·5	1	113	61	0	2	·0326
" " fl. measure	..	..	85				
2. " nitric	63	1	96	73	0	8	·1096
" " fl. measure ..	..	..	69				
3. " sulphuric	98	2	50	140	0	1½	·0107
" " fl. measure	..	..	28				
4. Ammonia	17	1	48	148	0	9	·0608
" fl. measure ..	..	..	55				
5. Ammonium chloride ..	53·5	1	56	125	0	6	·0480
6. " sulphate ..	132	2	70	100	0	3	·0300
7. Calcium chromate	349	2	60	116	0	7	·0604
8. Copper	63·5	2	33	212	1	0	·0566
9. " sulphate	249·5	2	126	55	0	5	·0900
10. Iron	56	2	30	232	0	2	·0086
11. Lead sulphate	303	2	159	44	0	6	·1363
12. Manganese peroxide ..	87	..	100	70	0	4	·0572
13. Mercury	200	2	100	70	4	0	·6857
14. Mercuric sulphate	296	2	150	46	4	0	1·0285
15. Potassium cyanide	65	1	100	70	3	0	·5144
16. " bichromate ..	295	2	300	23	0	10	·4290
17. " " ..	295	2	50	140	0	10	·0715
18. Silver	108	1	108	64	135	6	16·4062
19. " chloride	143·5	1	144	48	80	0	20·0000
20. " cyanide	134	1	134	52	80	0	18·5000
21. " nitrate	170	1	172	40	60	0	17·6914
22. Sodium chloride	585	1	60	116	0	0½	·0043
23. " nitrate	85	1	87	80	0	2	·0249
24. Zinc	65	2	34	201	0	4	·0195
25. " amalgamated	..	..	..	..	0	6	·0292
26. " sulphate	287	2	148	47	0	3	·0634
27. " and H_2SO_4 cell ..	..	..	365	..	..		·0438

1. HYDROCHLORIC ACID.—Variable in strength; good quality is of sp. gr. 1·16, and contains about 32 per cent. HCl.

2. NITRIC ACID.—This varies greatly through the various qualities sold as nitric acid, aquafortis—double and single, dipping acid, &c. The highest strength has a sp. gr. 1·5; ordinary good commercial is about 1·390 to 1·420, and contains from 65 to 75 per cent. HNO_3. I have taken the acid at 1·400, and as equal to 70 per cent.

3. SULPHURIC ACID.—This means concentrated oil of vitriol, sp. gr. 1·845, which is obtainable nearly pure.

4. AMMONIA, sp. gr. ·880, contains 36 per cent. NH_3.

15. POTASSIUM CYANIDE.—This is the white, which varies in quality from about 50 per cent. to 75, the highest which can be made, as the process involves the production of a proportion of cyanate. The quality is taken as 65 per cent.

18 to 20.—The SILVER SALTS are calculated as if made, allowing for labour, the silver being taken at 6s. per ounce troy. The cyanide is supposed to be simply precipitated and washed, not dried, and reckoned at 5s. per ounce. The chloride has an extra charge on it to pay for separation and fusion for use in batteries, and is therefore at the same price as the cyanide. *The chloride ought to be obtainable 3d. per unit cheaper, in fact at its worth in silver—that is, at 68s. per lb.*—as it is a product in silver working, and has to be reduced *for the sake of its metal.* Nitrate of silver may be bought at 3s. 9d. per ounce, the price in *the table.* *The cyanide should never be purchased, as it ought not to be dried.*

282. Table V. contains a list of the principal substances used in electrical operations, arranged to accord with the unit of "quantity" and of "current" used in this chapter, as explained § 170, showing the amount of each required for a chemic unit of electric quantity. The weight (col. VI.) allows for the ordinary impurities of commercial articles, and applies to materials not intentionally adulterated. The price (col. VI.) is such as the substances can be obtained at in the ordinary way (with the exception of the silver salts), and where a different price is paid the user can readily apply a correction to the unit cost (col. VII.) in any calculations.

Under the French system of weights and measures such a table would be far more useful than our system admits, as the figures for the small units would apply equally to the largest amounts used in practice, while in the English system one calculation is needed to convert grains into pounds, and then another to ascertain the cost.

TABLE VI.—COST OF BATTERY WORKING.

Name of Cell.	E.M.F. Volts.	Cost in Pence.		
		For unit Current.	Per Equivolt.	Per 1000 Joulads.
Copper-zinc	0·28	0·0438	0·1564	0·0247
Smee	0·50	0·0438	0·0876	0·0138
" odds and ends	0·50	0·0284	0·0568	0·0090
Daniell	1·08	0·0584	0·0543	0·0086
Nitric acid, 1st stage	1·8	0·2590	0·1439	0·0227
" " 2nd stage..	1·55	0·1025	0·0621	0·0104
" and hydrochloric acid	1·85	0·1360	0·0735	0·0116
Bichromate of potash	2·	0·1320	0·0660	0·0104
" and hydrochloric acid ..	2·1	0·1668	0·0794	0·0125
" single cell	1·8	0·2000	0·1111	0·0175
Manganese	1·5	0·2494	0·1663	0·0263
Lead sulphate	·57	0·1738	0·3049	0·0481
Sulphate of mercury	1·52	0·5337	0·3502	0·0552
Silver chloride	1·2	0·2000	0·1671	0·0263
" " per Table V.	1·2	3·6230	3·0192	0·4763

283. COST OF BATTERY WORKING.—The mode of using the table of costs will be seen in § 215. These costs are those of unit *quantity*. But to compare the real value of different cells we must take into account the *energy* of the combination as well. This subject will be explained hereafter, but the required information is given by dividing the cost per unit quantity by the E M F in volts which *gives the cost of 1* equivolt of electric energy 4673 *ft.-lbs. The unit in practical* use is the volt-ampere or joulad,

and I have shown the values in both terms in Table VI. Another point has to be considered in relation to economy, the relative internal resistances: thus while lines 1 and 5 show nearly equal cost for energy, the nitric acid cell gives the energy in a useful form, while the copper-zinc would require 7 cells in series to equal 1 Grove, and would waste the greater part of the energy within the cells, instead of as useful external work.

The work of 1 grain of zinc in any combination is given by multiplying 4673 by the E M F in volts and dividing by 32·6 the equivalent of zinc, or more simply by making this division at first, and multiplying 143·35 by the E M F.

284. The question is frequently asked, What is the best battery? The foregoing description will show that no answer is possible, for no such thing exists; each form has qualities adapted to particular purposes; each has also its defects, therefore selection must be made according to the intended work. The following classification will assist in the selection.

TABLE VII.—SUITABILITY OF CELLS.

1. NAMES OF BATTERIES.

1. Smee.
2. Daniell.
3. Nitric acid.
4. Bichromate.
5. „ Single cell.
6. Chromic acid.
7. Manganese cells.
8. Dry cells.
9. Mercury sulphate.
10. Silver chloride.
11. Magneto-electric machines.

2. USES CELLS ARE SUITED FOR.—*Large Currents.—Continuous.*

Electro-deposition	1, 2, 3, 6
Gilding	3, 6
Silvering	1, 2
Electro-magnets	6, 3, 1, 2
Electric light	3, 6
Temporary.	
Induction coils	6, 3, 5, 1
Medical coils	7, 8, 1 5
„ „ pocket	10, 9
„ „ continuous current	8, 9, 1
Small Currents and High Resistance.	
General telegraphs	2, 8, 61,
Occasional.	
Domestic bells and telegraphs	7, 8, 10, 1
Exploding fuses	11, 7
Testing resistances, &c.	5, 4, 7, 8

285. SECONDARY BATTERIES.—Most operations are reversible: a falling weight will drive clockwork, and the clockwork will raise the weight. So in chemical action oxygen and hydrogen combine and give up energy while forming water, and equal energy, applied by an electric current, decomposes the water (unburns it, in fact) and separates the gases. In this action the energy of one equivalent H 1 grain, O, 8 = water 9, is measurable as 6840 foot-lbs., and represents an E M F of 1·5 volt. Every chemical action which, giving up energy, constitutes an electric generator, can be reversed by a superior E M F, when it receives and stores energy. Such batteries are therefore called *accumulators*; they are also called *polarization batteries* because the E M F of plates in an electrolysed solution was attributed originally to some electric polarization, whereas it is simply the reaction of the chemical agents collected upon the plates.

286. In the Smee cell zinc displaces hydrogen as shown p. 104: let us reverse the direction of the force, adding also a molecule of water H_2O to be decomposed; then we have $ZnSO_4 + H_2O$ changed into $Zn + SO_4H_2 + O$; the zinc is separated, sulphuric acid formed, and oxygen set free, provided there is nothing for it to unite with.

287. In the Daniell cell zinc displaces copper from its sulphate $CuSO_4 + Zn$ becoming $ZnSO_4 + Cu$, generating an E M F of 1·079. By superior force we can reverse this process, and by electrolysis of zinc sulphate from a copper anode convert it into copper sulphate and deposited zinc. Hence a Daniell cell, when exhausted, can have a reverse current from a dynamo machine passed through it, and be fresh charged. This form of "accumulators" has been proposed, but is not practicable for reasons given § 318.

288. Reverting to the conditions of § 287, we have oxygen freed, and this is wasted energy: it may be saved by using a plate which will absorb the oxygen as a gas, such as porous carbon; or we can use a material which will absorb the oxygen chemically; such an electrode exists in the ordinary manganese cell § 263, for the sesquioxide of manganese will take up the oxygen again and reform the peroxide. Iron or oxide of iron will also act in this manner. Lead is, however, found most suitable, because, in the presence of sulphuric acid, lead does not pass into solution from the anode but forms peroxide, and this being a good conductor constitutes (§ 268) a powerful negative element.

289. Zinc, in the presence of acids or alkalies, or of most metallic salts, sets up *spontaneous* action; therefore the next step *towards an ideal accumulator* is to substitute some metal

not so acted upon; palladium has the property of absorbing 900 times its volume of hydrogen, forming with it a true alloy in which hydrogen apparently becomes a solid metal, and conducts electricity: but for the cost of palladium this would be a valuable electrode. Experience has shown that lead is the best available metal, and we thus come to two plates of lead in a solution of sulphuric acid in which water is electrolysed, the oxygen forming peroxide of lead, while the hydrogen is partly occluded in the porous lead surface, and partly employed in reducing lead from its compounds.

290. A slight review may now fix in the mind the principles involved, and the relations between "primary" and "secondary" batteries. In § 165 we have seen that the E M F originates in the attraction of zinc for the sulphuric radical of the acid, we have also seen that oxygen, &c., at the negative plate increases the force. Generalizing this by the aid of Fig. 34, p. 104, we see that there exists an attraction between the + plate and the − radical or ion of the electrolyte, and between the − plate and the + radical. These + and − properties and their consequent attractions may be inherent in the substances or may be produced temporarily by means of electric energy. In the ordinary battery the superior + quality of the zinc sets up the condition of polarization and renders the other plate − in condition, in polar order, and attractive power, *although its own nature is + as related to the acid*, but + in a lower degree than zinc is.

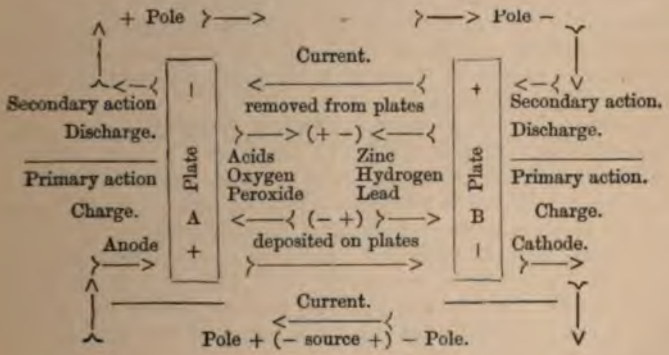
291. If then we use two plates equally + by nature, two zinc, two copper, two platinum, we have no polarizing force present: but if by any means we set up differential attractions at the plates, the force comes into existence. If we insert an electric source in the circuit, we polarzie the two plates in opposite directions, and give them this differential attraction for the ions of the electrolyte, to an extent depending on the E M F. Again, if we modify the plates by coating them with different substances the same effect is produced. If one platinum plate is lifted and exposed to the air its attraction for hydrogen is increased by the film of oxygen absorbed.

292. If we pass a current through two platinum plates in acid, we coat them, one with hydrogen, and the other with oxygen; these two films now become active agents, and their attraction for each other reacting across the electrolyte, sets up polarization. The same result follows from the presence at the two plates of any other substances having affinity for each other, a condition necessarily set up by any electrolytic action. *Thus with* lead plates, the hydrogen reduces any oxide and is *partially occluded* in the lead, producing a + plate of lead and

hydrogen, representing the zinc of ordinary batteries; the oxygen produces peroxide of lead, representing the nitric acid, or other oxidant.

293. It is important, at this stage to avoid some confusion about *poles* and *plates.* The same terms and the same ideas ought to be used in both kinds of battery: in the primary battery the term *plate* and its character as + or − refers exclusively to its relation to the electrolyte, and to direction of the current *within the battery.*

The term *pole* applies to the direction of current *outside* the battery § 167. But in the secondary battery the relation of the plates to the liquid changes according as it is charging or discharging: in the charging period it is not a battery, but a decomposition cell or a voltameter. I have endeavoured to show these relations in a diagram, in which the arrows of the upper part show the currents of discharge, and the lower ones that of the charging period: the small internal arrows show the direction of the ions of the electrolyte during the two periods.



294. There is, however, a tendency to call that plate + which is connected to the + pole of the source in charging, and which itself forms the + pole in discharging, that is the left side plate in the diagram, which is the peroxide plate. Professors Ayrton and Perry have adopted this course, as does Sir D. Salomons, with some hesitation, in his work on Accumulators; other authorities reverse the names.

The E. P. S. Co. colour the pole of the peroxide plate *red*, and speak of it as the positive pole, and it is not unlikely that there may arise a general practice of colouring the terminals, and also the conductors of the circuits on some fixed plan which will practically dispense with the confusion over positive and negative. The editor of the 'Electrician' suggests "The *P*ositive plate of a battery is properly so-called because it is *P*eroxidized and *P*lum-coloured: the *N*egative plate, on the other hand, is of a *N*eutral colour, and is *N*ot oxidized."

295. At all events if a secondary battery is connected to the source, and an external circuit is also connected just as shown, the plate A becomes a constant + *pole* to this external circuit: but a complicated set of conditions arise: in fact the cell and the outer circuit act as derived circuits to the source, and it depends upon relative forces and resistances what course the current takes: no current enters the cells unless the conditions are such that the difference of potential set up between the plates A B exceeds the E M F the cell itself could generate, therefore if the external circuit were one of small resistance, the current might altogether pass to it: if the external circuit is broken, the cell receives charge from the source, and on the circuit being closed the source and the cell act together in sending current to it. In this way a secondary cell would act as a true accumulator, and fulfil the functions of a fly-wheel in mechanism. This is probably the true use to which secondary batteries will be mainly applied. But in most cases automatic commutators would be required to vary the connections to suit the changing conditions.

296. HISTORY.—The reverse current from the plates of a voltameter was first observed in 1801 by a French chemist, Gautherot. The same observation was made in 1803 in Germany by Ritter, who made a pile of plates of gold, separated by cloth moistened with acid, and subjected to the action of a Volta's pile of sufficient plates to send current through. The first theory was, naturally, that the electric fluid was soaked up by the plates; that it was an action of surfaces receiving charge, and that the secondary pile was analogous in its actions to a condenser.

The chemists, and notably Becquerel, soon traced the action by means of saline solutions to the presence of acid and alkali at the opposite plates, and in due time, the discovery of Grove's gas battery convinced the scientific world that the return current was not due to an accumulation of *electricity*, but to the presence of substances having chemical affinities to each other, derived from the previous decomposition: and that the counter current was generated on the same principles as that of the ordinary galvanic cell: it was merely a different mode of charging a cell with its active ingredients.

297. The subject was studied by many, and nearly everything

that is known even now, was discovered long ago; but it was simply a matter of scientific interest and theory with the possibility of some very limited applications. Among these Mr. Cromwell F. Varley employed a series of zinc and carbon plates mercurialized (the Marie-Davy cell, § 228, reversed) to take a slow charge, and deliver it up in a short strong current for sending time signals. In 1861 Kirchoff devised the form which is the basis of the latest improvements, peroxide of lead opposed to spongy lead.

298. In 1859 Gaston Planté found that the best effect was produced by two sheets of lead in dilute sulphuric acid: he worked out a system of formation by which he greatly increased the capacity of the plates, and published to the world a number of highly interesting scientific results obtained by a great series of his cells with the aid of subsidiary appliances for converting series into multiple arc, and with condenser plates charged from the accumulators, by means of which the energy derived from a couple of Bunsen cells was enabled to produce effects which would have required thousands of such cells in series to produce. M. Planté studied the subject exhaustively, discovered pretty well all there is to know about lead secondary batteries and published it to the world. He is a striking instance of a man doing thoroughly good work, and doing it with little profit, while others, taking up his labours, have patented every imaginable variation in the form and arrangement of his battery and obtained in some cases large sums of money therefrom. But Planté's name will be associated with the secondary battery when these are all forgotten.

299. Real interest in the storage battery dates, however, from May 1881, when Sir W. Thomson published a letter in the 'Times,' announcing his posssesion of a "marvellous box of electricity," in which "a million foot-pounds of energy" had travelled from Paris to Glasgow, and which box was stated to be the "practical fruition" of electric storage, and was to do "for the electric light what a water cistern in a house does for an inconstant water supply." The public and the general press, ignorant of the fact that the large sounding million foot-pounds only represented the potential energy of about 1½ ounces of coal or the energy developed by an ordinary steam engine with 1 lb. of coal, became greatly excited, and, in no great time, the million foot-pounds were converted into a million pounds sterling (more or less) to be invested in the invention.

300. The wonderful box of electricity consisted of lead plates coated with a paste of red oxide of lead, minium, held to the surface by means *of a wrapping* of felt. It was in fact a Planté

battery, upon which M. Faure had applied this coating in order to arrive at, 1, a quicker result by doing away with the need of the process of "formation"; 2, a greater capacity in the same space, by means of the larger bulk of the oxide ready for immediate action. Then followed a host of "inventions," some of which were associated with the first, directed to 1, securing the contact and adhesion to the lead plates of the spongy mass of oxide; 2, obtaining the spongy mass from different materials: and 3, of developing the original Planté system and enlarging the surface of the lead in a given space. A few have attempted other substances, but so far experience confirms M. Planté's own experience, that nothing is practically so good as the two lead surfaces in acid. But the storage battery is still a very long way from fulfilling its promises, though it does good work, and may be expected to do much better when the earlier patents no longer stop the way.

For obvious commercial reasons the ordinary Planté form is rarely made for sale, because any one can sell it, and it has disadvantages. But as my readers are largely of that class who like to make their own apparatus, I shall explain the nature of this simple form, the principles of which underlie all the others. Also, where space and weight are not serious considerations, I believe it will be found that this earliest and simplest type, the plain sheet of lead with thin active films formed upon it, will be found very efficient.

301. *Construction.* The early forms consisted of two thin sheets of lead with felt or other porous material between them, rolled into a cylinder, and placed in a jar. This make may have its uses for amateurs on the small scale; but if adopted the felt should be replaced by strips of vulcanised rubber placed diagonally and in opposite directions, between the two sheets, so as to support the lead in a sort of lattice work.

302. *Flat plates* are much the best, the alternate ones connected together so that, whatever the number of plates, they act as one pair of plates in each separate cell. The best way to cut the plates is to make them in pairs, that is to cut the lead first into pieces twice as long as the intended plate, and an inch wider; mark the middle, then cut down to this mark from the opposite sides at the two ends, leaving the extra strip, and between these cut along the mark; this gives two plates, each provided with a long connecting strip forming part of itself; it is better not to make the cut a sharp angle, but to curve it where the strip leaves the plate.

303. The plates are to be arranged in the vessels with the *strips alternately* on each side, and with one plate more on one

side, for the spongy lead plate, as only one side of the outer plates is acted on.

The strips on each side are then to be all brought together and firmly clamped with a connection to unite the cells together. It is even better to tin the strips and solder them together with a connecting strip of tinned copper, and then to thoroughly varnish them.

The plates can be suspended either by a rod running through the joints of the strips, or by a cross bar of ebonite, or well-paraffined wood, fitted under the joints, and supporting both sets; they should leave a clear space of 1 or 2 inches in the vessel below the plates.

304. *The thickness of the lead* must be sufficient to bear its own weight and the strains put upon it after use: the peroxide plate should therefore be about double as thick as the other: in large batteries lead 1 millimetre thick is used, which is ·03937 inch, or about 24 sheets to the inch. One square foot of lead 1 inch thick weighs 59·1 lbs., therefore this would be about 2¼ lbs. lead. The smaller cells are made of lead little thicker than that prepared for damp walls, which is about 4 to 5 ounces per foot. For ordinary purposes it is probable that sheets of 1½ lb. and 1 lb. would be most advantageous, with the formation carried so far as to convert ½ lb. of the lead per foot, to peroxide on the one plate. But for heavy work, and where first outlay is not of moment, 4 lb. and 3 lb. lead is the best and cheapest in the long run.

305. *Separating strips* are desirable, and may be of paraffined wood, india-rubber, or any convenient non-conductor. In the heavy grids, porcelain studs are used, and a convenient separation may be adapted to plates, by cutting at regular intervals, on the spongy plate, holes half an inch long, and a quarter wide, spaced exactly alike on all the plates, and putting in them H pieces of thick india-rubber an inch long, with the cross piece half an inch long, so as to fill the holes.

The whole set of plates should be firmly bound together, with supporting strips of wood so as to be placed in or removed from the cell conveniently.

306. *Space for acid* must be allowed, sufficient to effect the action, therefore the distance of the plates must be properly adjusted: circulation cannot be depended on, but the bottom of the plates should have a space below them, and their tops should be under the liquid, in order that the heat and escape of gas may produce a current, and draw the external acid between the plates. One pound of lead requires *½ lb. of* acid to convert it into sulphate, and as *by the proportions given* above there would be ½ lb. of

lead to be converted per square foot, this requires space for ¼ lb. of acid, which would be contained in a space of ⅓ of an inch between the plates. Even larger space is desirable. In order to prevent the spurting of acid, it is well to provide sloping plates of glass above the plates, supported by a bar crossing the middle of the cell. Another plan is to pour melted paraffin on the liquid, so as to form a solid covering; oil has also been used but does not altogether stop the spurting.

307. *Containing vessels* may be of any suitable material, but glass has the great advantage of permitting the action to be watched: if lead vessels, or wood lined with cement or other opaque vessels are used, they should be covered with sheet glass for this reason. They must not be entirely closed, because gases are generated and must be allowed to escape; they should not be uncovered, in order to resist evaporation and also for prevention of dirt which would be likely to result in short circuiting the plates, a thing very likely to occur and obviously injurious to the working.

308. *In mounting batteries*, great care should be taken to insulate them thoroughly: they should not stand on a floor or shelf, but on a frame of two bars, thoroughly cemented with pitch; the cell should not even stand directly on these, but upon insulating feet, themselves standing in a cup of resin oil. This care will be well repaid by economy in working, and general satisfaction.

309. *The strength of the acid* varies during the action, becoming strongest when the charge is complete and one plate is converted into spongy lead and the other into peroxide: when discharge is completed a great part of the acid is absorbed in forming sulphate of lead. Several consequences result: 1, the resistance of the battery is lowest just when its E M F is highest and *vice versâ;* where the material consists of a porous mass, containing liquid confined among its interstices, the acid may be exhausted long before the material itself. As a consequence, a cell containing a large mass of active material may be able to do but little work: this defect is also an accumulative one; portions of the mass become practically non-conducting and insulate other portions to which the acid has access, because in very dilute acid instead of the normal sulphate $PbSO_4$ there is a tendency to produce the basic sulphate $PbSO_4 + PbO$ which is not readily reduced by hydrogen. The simple Planté form, with its thin film of active agents presenting a large surface freely bathed by circulating liquid, is not subject to this; which is the cause of the failure of many of the patented batteries. The practical effect is that the cells should contain an ample supply of liquids, and every facility should be given to circulation.

310. *The chemical actions vary* with the strength of the acid, and it is found that the best strength corresponds to a sp. gr. 1·220, and the strength should not be allowed to go below 1·150. A hydrometer gives in fact the clearest guidance to the condition of the battery, and is in regular use in all practical operations.

Sulphate of soda was added to the solution by Mr. Barber Starkey, and is strongly advocated by Mr. Preece as a preventive of sulphating. The solution he finds the best is 12 fluid ounces of sulphuric acid added to a quart of saturated solution of common washing soda well stirred: 1 part of this added to 19 of water, and 5 of sulphuric acid gives the working solution of sp. gr. 1·210.

311. FORMATION.—In all forms of the lead secondary battery, the essential point is the presence at the one plate of a supply of peroxide of lead, in *quantity* adequate to the work, in *condition* to do it effectively; the difficulty is to unite these two. When a current is first passed between two sheets of lead in sulphuric acid under an E M F of 2·5 volts, a thin film of brown peroxide of lead forms on the anode; then oxygen escapes and no more peroxide forms: the reason is that the peroxide being a conductor of electricity, the action occurs at its surface in contact with the liquid, and this surface can undergo no change by the oxygen generated there. Only a very small charge can be stored or given up as a current. If at this stage the current is reversed, first the peroxide is reduced to lead, which is in a more porous state than at first, and a thin coat similar to the first is produced on the other plate. A fresh reversal allows a larger quantity of peroxide to be produced on the first plate because its granular state presents a larger surface and holds acid within its pores. After a few such reversals the limit of this increase is reached, and then it becomes necessary to allow a period of rest after charge. Now *local action* occurs between the surfaces of lead and lead peroxide in contact in presence of acid: the same conditions existing there as enable the two separate plates to generate a current.

312. This action, the source of the E M F of the secondary battery, is the tendency of the second atom of oxygen in PbO_2 (which atom has in fact been forced into the molecule) to pass over to the lead surface, and there produce the more normal protoxide PbO, thus rendering both surfaces alike: other actions follow, but this transfer of oxygen from the peroxide to the lead is the essential action. But this occurs in the presence of sulphuric acid which unites with the newly formed protoxide of lead, *producing sulphate of lead*, in a white film insoluble in

the acid. We have in fact first $Pb + PbO_2$ becoming $PbO + PbO$ and then $PbO + H_2SO_4$ becoming $PbSO_4 + H_2O$.

313. *Reduction of lead sulphate.*—On now reversing the current the spongy films of peroxide and sulphate of lead are penetrated with acid, which therefore is in contact with the lead surface, and when decomposed, presents its hydrogen to the sulphate of lead which is reduced to lead in a spongy condition. This decomposition of lead sulphate was doubted at first, but it is the basis of the action of the sulphate of lead battery, § 225, well known for many years. Messrs. Gladstone and Tribe proved that when two plates coated with $PbSO_4$ have current passed between them, not only is the lead sulphate on the cathode or −plate reduced by hydrogen to grey spongy lead, $PbSO_4 + H_2 = Pb + H_2SO_4$, but that the oxygen converts that on the anode to peroxide, $PbSO_4 + O + H_2O = PbO_2 + H_2SO_4$, regenerating the acid at the same time. Since then there have been many discussions about the reaction, and many different opinions expressed as to the nature and order of the changes which occur during charge and discharge, but it appears that the true action is that described above—the transfer of oxygen through the agency chiefly of lead sulphate.

A series of such reversals therefore converts the surfaces of the lead plates into a mass of spongy lead capable of ready conversion into peroxide of lead. But this mass of spongy lead, and also the peroxide coating its surfaces, is in actual molecular contact with the lead plate itself; it is not merely in mechanical contact with the lead plate, but an actual part of the plate. It is in this fact that the principal advantage of the simple Planté consists: but the same chemical principles apply to all other forms.

314. *Time of formation.*—The directions of Planté are to effect six or eight reversals of current the first day, prolonging the successive charges: this is to be continued the next day till the duration of useful charging becomes a couple of hours: at this limit it becomes necessary to give intervals of rest between the charges, during which the local action described § 312 takes place: these rests require gradual prolongation to several days. When the cell approaches its intended limits of capacity, the completion of its formation can go on gradually, during actual work.

315. *Heat* assists the formation and reduces the time required for the process: therefore during the charging the temperature may be raised to 160° Fahr. But heat is objectionable in actual working, because it facilitates the oxygen and hydrogen assuming the gaseous state and going off to waste.

Alcohol added to the extent of 5 per cent. to the acid solution is said to assist the formation.

Nitric acid is recommended by Planté, who says that by soaking the plates for some hours in nitric acid mixed with equal volume of water, he greatly reduced the time of formation. The effect is to produce a porous surface more quickly acted upon.

Amalgamation of the lead has been employed and is patented by Paget Higgs, who claims its first use. It is by no means clear that it is an advantage in the Planté form, though it is said to be useful in the case of grids packed with oxides.

Sulphate of manganese in small quantity is also said to assist the formation.

316. *Modifications of Planté's battery* have been devised in great numbers. Some have packed the spaces in a jar containing a porous cell with granulated lead, or fibrous lead, or sheet lead cut into narrow strips except at the top to keep up connection. They have usually proved to be nuisances.

De Meritens' cell was the first modification of the Planté. The plates are formed of thin sheets of lead placed one over the other like the leaves of a book, cut off in slices, and the ends soldered together to unite them. The result is a block of lead about one-third of an inch thick with a vast number of slits in which the action is carried on, and which become filled with peroxide of lead in the one block, and spongy lead in the other. This gives much concentration of material, but the formation has to be effected as in the Planté, while it is evident that the action is limited by the amount of liquid which penetrates between the films of lead.

Kabath's cell is a modification of the Meritens; it consists of similar plates built up of thin sheet lead, but these strips are passed through a pair of rollers which produce diagonal corrugations. These being interleaved with plain strips, the plate is composed not of surfaces in close contact, but of a series of small tubes sloping upwards and tending to produce a circulation of the acid throughout the plate; this appears more promising than the plain strips, but in all likelihood the tubes would soon be filled up.

317. *Messrs. Fitzgerald, Crompton*, and others united in producing a battery plate composed of a thin sheet of lead with a coating of spongy lead, derived from the electrolysis of chloride or other salts of lead, submitted to a pressure by which the particles of lead are to some extent welded together, and made coherent. They also used, as the *hydrogen* plate, a mixture of carbon and red lead.

It should be understood that I am describing devices which have no great practical success for the benefit of experimenters, to whom it is an advantage to know what others have tried. This carbon mixture is rather tempting, as carbon absorbs gases, so that it may be useful to know that it does not answer at the oxygen plate, as nascent oxygen acts on the most refractory forms of carbon, but that it does serve a purpose (whether worth serving or not) at the hydrogen plate.

318. *Other Metals* have been tried, and no doubt will be again, so a few words may be useful. Mr. Sutton proposed a lead plate to be peroxidised and a copper to be alternately dissolved and deposited from the sulphate formed. I also tried the combination of lead and zinc at an early date, and Regnier has claimed great things for it since. But such combinations fail on any large scale for the reasons to follow.

Metallic solutions do not answer in practice for the reason that I have had frequent occasion to refer to. The action, unless very slow, alters the layer of liquid in contact with the metal, which then refuses to act: in charging, after the first action there is no metallic salt present to decompose, but only acid which gives off gas, and so the metal deposit becomes noncoherent; in discharge, the metal salt forms too rapidly to dissolve, and crystallises on the plate.

Acid solutions other than sulphuric might be used and no doubt will; but hydrochloric acid when electrolysed does not give up H and Cl simply, it is always accompanied with oxygen, and the result is the formation not of chlorides, but of oxychlorides, which are exceedingly refractory in reduction: for this reason the chloride of silver battery fails in reversal, or else it would constitute an admirable storage battery.

Alkaline solutions cannot be used with lead because they dissolve it, but they may be employed with some other metals, as iron, which at one plate would absorb H and form peroxide at the other, forming a battery of rather low E M F.

319. FAURE'S BATTERY.—This, which is the wonderful box of electricity mentioned § 299, is the Planté cell in which the process of formation is nearly done away with by coating the plates with a paste of red lead, converted by electrolytic action into spongy lead and peroxide of lead. All the remarks made as to lead batteries, therefore, apply to this as to the simple Planté. It is the foundation of all the various forms of secondary battery which have been devised since.

At first, this cell was made, of necessity, with some material *such as felt,* asbestos cloth, &c., to bind the material to the *plates. These all* add to the resistance, resist circulation of liquid, and sooner or later rot away and disintegrate. By the combination of the patents of Swan, Sellon, and Volkmar with that of Faure, this battery assumes the form of small masses of the porous material contained in spaces in lead plates. There are a variety of means of effecting this, such as making the plates of an open network, or of perforated sheet; but the whole question resolves itself into the thickness of the porous mass which can be used to advantage; and its proportion to, and effectual securing to, the lead conductor.

320. THE E. P. S. BATTERIES, made by the Electrical Power Storage Company, are the outcome of these combined patents and several years of careful study of the conditions of working. After many failures, they appear to have arrived at a practically satisfactory construction, modified to suit the special requirements of various applications. The list of the makes suited to most general work may be useful.

Class and No. of plates.	Rate in Amperes.		Capacity in Ampere hours.	Charged weight in lbs.
	Charge.	Discharge.		
7 L	10–13	1–13	130	68
11 L	16–22	1–22	220	101
15 L	25–30	1–30	330	128
23 L	38–46	1–46	500	211
31 L	50–60	1–60	660	265

These plates or grids are rigid enough to carry their weight without injury when resting on supports at the bottom of the cell: recent improvements have consisted in increasing the number and reducing the size of the holes, so as to bring the active material into closer contact with the conducting plate, and in so shaping the holes as to resist the tendency of the pellets to fall out. The peroxide plates are charged with red lead and the spongy plates with litharge, which are electrolysed into the proper condition. It is found that these cells give a return of current 85 to 90 per cent., and of energy 75 to 80 per cent. when properly worked. According to Mr. Preece the efficiency or useful return depends very much upon the rate of discharge, which should not exceed a current of 4 amperes per positive plate. With largely increased rate of discharge, the efficiency may fall to 50 per cent., and the battery would suffer serious injury.

321. *Woodward's* battery, introduced by Messrs. Shippey and adopted by Mr. Crompton, consists of a grid of lead cast upon a mass of large *crystals of salt*, so as to create a honey-combed

structure, which may be either formed as in § 311, or charged with lead oxides. Mr. Crompton states that he can obtain without injury a current of 9 or 10 amperes per square foot: but the time of discharge depends so largely upon the gross quantity of active material that is not easy to fairly compare different makes.

322. *Lithanode*, described § 308, makes an excellent plate in secondary batteries, and is more especially adapted for small portable cells, where it is close upon perfection: it would be so for large cells also if the connection to it could be made of lower resistance.

323. *Capacity*, or relation of work to weight, depends upon construction as well as upon materials. Mr. Preece says, "I have had a cell (Fitzgerald's Lithanode) which gave a return as high as 5·7 ampere hours per lb. The average E. P. S. cell gives a capacity of 4 ampere hours per lb. of plates complete, while the Planté type rarely exceed 2 ampere hours per lb." Lithanode itself has a capacity of about 1 ampere hour per ounce.

324. *The electromotive force* of all forms of lead cells is about volts 2·2 immediately after charging, though it rises higher than this during the full charging; it falls in working, but should not be allowed to fall below 1·8 as the mischievous reactions set in then. The voltage of a battery should be regularly tested, and whenever found to be too low, each cell should be tested to discover where the faulty one is. Under careless management it is easy to have some of the cells reversed.

325. *The internal resistance* is constantly varying with the strength of the acid §309, and also with rate of current as it does in all electrolytic actions. Mr. Preece draws from this the deduction that there is not the generally supposed loss due to the difference of E M F in charging and discharging, but that "it is possible to get nearly all the energy out of a cell that has been put into it." Mr. Preece is "one who knows," and what he says is usually to be relied on; but in this case I think the estimate of the E. P. S. Co. (not likely to put it too low) of 75 to 80 per cent. is the safer to count upon.

326. *Charging.*—In order to charge a secondary battery it is necessary to employ an E M F greater than its own, and greater in proportion to the rate of charge desired. If 20 per cent. of this energy is lost slow charge is most economical, though other practical considerations have to be taken into account; that is, against energy lost at the rate of the square of the current C^2 generated, we have to consider time, and interest on plant. But in addition to the loss of energy, a small charging current *is desirable for two* reasons, 1, the product is in better condition,

the particles in closer contact and better electrical connection: 2, there is less loss by uncombined gases escaping.

Volts 2·5 per cell in series is a good E M F, as with it the current reduces as the charge rises, on account of the increasing counter E M F of the battery.

At first it was thought unadvisable to give cells their full charge; but experience has proved this to be wrong. *The battery should always be thoroughly charged*, but not thoroughly discharged. By not fully charging undecomposed sulphate of lead remains to exert noxious action.

The evidence of full charge is—

1. The E M F rises suddenly to volts 2·5.
2. The hydrometer shows the acid at full sp. gr.
3. The liquid becomes milky and gases are given off.

Lights should not be brought near a charging battery, lest these gases should cause explosion.

326A. *Loss of gases.*—Throughout the charging there is a constant escape of gases, chiefly oxygen. But the loss of either gas means total loss of the equivalent of electricity. If O is obviously wasted, it is certain the H is lost too. But the escape of H indicates at once either that the rate of charging current is too great, or else that the limit of the economical charge is approached. As in all cases of electrolysis we are brought to the question of *density of current*; the rate at which a unit area of surface can act properly; this is of necessity a *lowering capacity*, because it is not mere surface we have to consider, as in the case of the zinc of a battery, but the diminishing quantity of sulphate of lead upon that surface remaining unconverted. But this evolution of gas is the best practical indicator of the working conditions.

327. *Discharge* should not be allowed to exceed the proper rate, or the active material will disintegrate and be shelled off in the Planté or forced out in the grid forms. Discharge should not be continued after the voltage falls to 1·8 per cell.

328. *General Management.*—Batteries should be so placed and mounted that every part is visible and accessible; regular tests should be taken of the condition of each cell, and no tricks should be played, such as suddenly heating wires, or giving off flashes of light. See also § 308.

Proper instruments, galvanometers, voltmeters, &c., should be provided, and the connections made through a well arranged switch-board. Automatic cut-outs, alarms, &c., also are very useful. These various appliances will be found described in their proper places, but the best plan for any one who wishes to set up an installation, is to obtain catalogues and pamphlets from the makers, in which more complete information will be found than it is possible to furnish in a book like this.

It is bad economy not to provide cells fully equal to their work, and it is important that all cells to be worked together shall be fairly equal; for, as in a chain, the capacity of a combination is that of the weakest link: if some cells become inactive in discharge, they are not merely useless, they begin to take charge in the opposite direction and oppose their E M F. If cells in multiple arc differ in E M F, which will occur if their conditions differ, some of them will not get charged, or if left so connected when the source is not acting, they will be reversed and the charge wasted. In fact it is bad policy to arrange cells in multiple arc at all.

When a battery is to be left out of use for a time, it is better to fully charge it, rather than leave it discharged. Current should be passed at intervals to keep up the charge if possible.

Since the foregoing was in type, accounts have been published of the working upon tramways in America of a secondary battery devised by Messrs. Waddel, Enty, Foote and Phillips. It consists of a plate built up of copper wire, which serves as conductor to a mass of compressed porous copper, which is oxidized by the charging. The other plate receives a deposit of zinc from a solution of zincate of potash. It is said to hold charge perfectly, give an E M F of volt 0·8, to give a return of 80 per cent. energy and no loss of current, and to endure a heavy rate of discharge. No gas is given off, either during charge or discharge. The internal resistance of a cell of 5 × 7 inches square and 11 high, containing eight pairs of plates, is ·001, and its storage 800 ampere hours, with a gross weight of 55 or 60 pounds per horse-power generated.

CHAPTER V.

MEASUREMENT.

329. The great distinction between modern and ancient modes of investigation is that modern science is based upon exact, minute measurement, so that causes and effects are truly balanced and actions traced from point to point; then when different branches of phenomena have been traced to their connection, an explanation, a *theory* can be arrived at: the science "falsely so-called" of the ancients was vague, the theory or conception was first set up *a priori* from a general view of phenomena, and then the facts were fitted to it as well as they could.

But just as old fashions in dress are revived in time, and in mental affairs there is at times a reversion to mediæval ideas, so there is at present a tendency among some of our highest scientific men to reverse the course of science, to abandon the Baconian inductive system, and return to the old *a priori* plan of devising hypotheses and treating them as truths. This is particularly manifest in the prevalent fashion of attributing electrical actions to the *ether*, rather than of searching out the real actions of *matter*.

330. Clerk Maxwell gave the start to this mischievous fashion; his disciple, Mr. Oliver Heaviside, has gone so far as to say ('Electrician,' xxvi. p. 633), "The more abstract a theory is, the more likely it is to be true. No one knows what matter is, any more than ether, but we do know that the properties of matter are remarkably complex. It is therefore a real advantage to get away from matter when possible, and think of something far more simple and uniform in its properties. *We should rather explain matter in terms of ether, than go the other way to work.*" The italics are my own. The doctrine is monstrous and opposed to all true science; for science is organised *knowledge*, a steady progress from the known to the unknown. This is teaching that we should start not merely from the unknown, but from the unknowable; for not only do we know nothing at all about ether except that something *transmits* light across space, but it is *absolutely beyond reach of* experiment, the only means of

knowledge. All that is said about ether and its properties is mere guess-work.

331. It is a mere misuse of words to say that we know no more of matter than of ether: as I said in the 'Electrician,' xxvi. p. 672, in reply, "We do know what we mean by matter; no one knows what they mean by ether." It is pure cant to say that we have no right to object to notions about the ether because we do not know what matter is. We do not know, and never shall know, what anything is, nor does it concern us. "We know a great deal about the properties of the thing we mean by the word matter, and we can examine and test those properties. Nothing of this is to be said of the ether. The word matter connotes a mass of natural obvious records of our cognition. The word ether connotes nothing but our difficulties of defining some of those facts." In other words, matter and its properties are the creation of God; ether and its properties are the mere imaginings of men to hide their ignorance, and they are being continually altered to suit any one's requirements. *Prove all things*, hold fast that which is true, is good advice.

332. Electrical measurements relate to the three divisions, electromotive force, resistance, and current, and the general theory will be explained further on, but it is better to commence with the facts the theory is based upon, and the instruments in use, following, in fact, the process by which the existing system has been developed, and commencing with the actual phenomena of current. It should be understood that the multitude of instruments which have been devised are not described: it would need a volume. Only those necessary for students and amateurs will be mentioned, and most attention will be given to those which, with ordinary skill, they can make for themselves.

333. MEASUREMENT OF CURRENT.—This may be effected by three actions of the electric current, § 164—the *magnetic*, the *chemical*, and the *heating* effects, examined by instruments called *Galvanometers*, *Voltameters*, and *Calorimeters*. Each has its use. The galvanometer interferes little with the passage or work of the current, and indicates, by the motion of a magnetic needle, the actual current passing at each instant, and therefore any variations occurring; the voltameter measures the total quantity of electricity which has passed in a given period; and the calorimeter testifies to the relations of energy to the electrical work done.

334. GALVANOMETERS.—When a magnetic needle and a current are parallel with each other, they tend to place themselves at right angles to each other; the action is reciprocal, either the

magnet or conductor will move, but the motion of the needle is the most convenient for use: if *over* a magnetic needle at rest, and in the same direction, we place a wire, and pass a current entering at the southern end, the needle turns with the N. end to the left, or westerly; if the wire be *below*, the needle turns to the right. If the direction of the current is reversed, that is, if it enters at the N. end, the actions are reversed. If the wire makes a turn round the length of the needle, all these conditions come into play at once, for the current entering at S. and passing *above* the needle, when the wire turns to the lower side, the current passes from the N., hence both actions are the same and the needle is deflected to the left with double force; each turn has a similar action, varying, however, in amount, with its distance from and position as regards the needle, on principles explained hereafter.

335. GALVANOMETER NEEDLES.—These are frequently made too heavy; the heavier they are the greater is their "moment of inertia," and the force required to move them, and the longer they are in coming to rest. The best material is a watch or clock spring softened, in order to shape and arrange it, then hardened by heating to a low red heat and plunging in water.

Long needles have most directive force and give more decided indications, but take longer in coming to rest; they are therefore best adapted to vertical galvanometers. Short needles are less affected by external magnetic disturbances and come quicker to rest; their deflections are also more equal in value at different parts of the scale. Therefore long and heavy needles are suitable for "ballistic" galvanometers, or to give the average of a rapidly changing current; but short light ones are better to obtain "dead beat" and sensitive indications.

336. *Magnetizing* may be effected as described §§ 142–3. The best plan is to make a coil to suit the needles, but in two parts, which can be slipped over each end; this enables needles when mounted, or in pairs, to be magnetised. If the coils are made of No. 20 or 22 wire, a single bichromate cell will do the work effectively. The coils should be marked to show which end gives N. polarity when connected to + of the battery: astatic pairs are inserted separately in opposite directions.

337. *Suspension.*—For delicate instruments, the only satisfactory suspension is by a silk fibre, or such a thread of silk as may be drawn from a ribbon, or piece of covered wire. The fibre should be attached at its upper end to a sliding rod (in good instruments a compound screw is used) which lifts without twisting the fibre. For ordinary instruments, with a single

needle, an agate centre fixed above the needle is used. Double needles may be suspended in a similar manner; the agate centre is first fixed in a thin brass tube by turning the edges lightly over it, the upper needle is then attached to it; if double, by placing one part on each side; if single, either by a hole opened in the middle or by doubling over the top and bringing down on each side so as to grip the tube firmly, and then touching lightly with solder, or an indicator may be similarly fixed. The lower needle may be made of two pieces of watch-spring, one fixed on each side of a very thin light tube, the ends of the needles drawn together and soldered or riveted. The tube should be under $\frac{1}{4}$ inch in bore and fit firmly on the tube carrying the agate, and when the two needles are exactly adjusted a touch of solder will fix the tubes together. To adjust the needles, a suspension point is placed upon a movable board having a line marked upon it; one needle being magnetised, the line on the board can be placed true N. or S., and the other needle or indicator being added, the tubes are moved slightly till the united system is correct.

338. *The swings of the needle* correspond to those of a pendulum, and for the same needle always occur in the same time, whether the swing be across the whole arc or over only a degree or two: this gives a means of adjusting astatic needles to the desired delicacy, and also of controlling the movements of needles. It is easy to make and break circuit with a commutator or key, so as to lead the needle slowly up to the proper deflection with scarcely a return swing, or to meet the swings and bring it to a dead stop, which saves much time in observations; but the number of vibrations of a needle may be diminished or arrested by *damping* in various ways.

(1) A plate of copper close to the needle, either as the dial plate or as the internal frame of the coils, checks the swings by the induced electric currents set up in the copper.

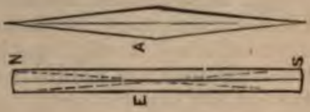
(2) A vane of paper or mica may be attached either to the needle or indicator.

(3) A similar vane may be attached to the bottom of the wire which connects the needle to its fibre, to work in a chamber under the coils; sometimes this chamber contains mercury or some liquid, such as glycerine and water, the effect of which is to cause the needle to move slowly up to its point of rest without swinging; or the chamber within the coils may be so used.

339. *Needles should be formed* with points tapering to near the middle: the ends should not be square, because the current acts on the magnetism, and tends to pull the poles over to the

corners as shown Fig. 38, and to disturb the relation between the needle and the indicator (see § 150). When formed of thin plates on edge this cannot occur, and the shape is of no consequence. In some tangent galvanometers compound circular needles are used, consisting of a disc of mica on which parallel strips of steel, such as pieces of sewing needles or watch-springs are cemented, long in the middle and shorter at the sides: it is considered that these suffer less displacement in the magnetic field of the current than straight needles do.

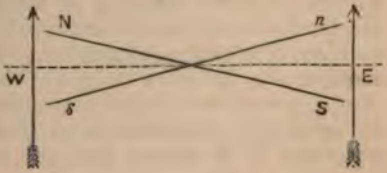
Fig. 38.



340. *Indicators* may be made of a thin, hard-drawn wire, aluminium alloyed with a little silver being best, or of a thread of black glass, which may be drawn out over a Bunsen's burner or spirit lamp, by heating a small rod or tube (such as a bugle) to fusion, and drawing the two ends rapidly but steadily away. An indicator without weight, used in the reflecting galvanometers is described § 368.

341. Astatic Needles are a pair fixed on a wire or a tube with their poles in opposite directions, so as to neutralize each other: if perfectly adjusted they would have no particular position of rest. It is often stated in text-books that such needles place themselves E. and W., and an elaborate mathematical explanation is given. Fig. 39 explains the cause simply. N S are two oppositely arranged needles, not exactly in the same vertical plane (this being exaggerated in the figure): the result is to form two virtual magnets or fields at the opposite ends, both having the same direction, as shown by the arrows; these place themselves in the usual N. S. position, and as a consequence, the visible system, which is a neutral one, places itself E. and W. This occurs only when the needles are exactly equal. In practice it is necessary to make one of the needles so much more powerful than the other as to bring the system to rest upon the zero line: the upper needle if made longer does this by its greater "moment."

Fig. 39.



The magnetism of astatic pairs is easily disturbed; any current passing will do it, if sudden or over strong; the inner needle is most affected in this way. In consequence of this, astatic needles indicate, but do not measure, because different readings may be given with the same current, even in a few minutes. This applies more especially to vertical systems controlled by gravity, or springs.

342. *Magnetism of needles.*—The strength of the magnetism has no effect upon the deflection; two similar needles will be alike deflected, though one be strong and the other weak. The reason is that the needle is affected by two forces, the effort of the current and the earth's magnetic field, and these are equally reacted on by the needle. This applies only to single horizontal needles. A compound pair will deflect differently when strongly and weakly magnetized. A needle vertically suspended will also deflect further if strong than if weak. Needles of different length will be differently deflected by the same instrument and current.

343. *Resistance to motion.*—The actual measuring power is due to the resistance offered to the action of the current. In the ordinary single-needle instruments, this resistance is caused by the earth's magnetism; the result is due to the relative strength of the two magnetic fields, earth and current, acting at right angles to each other: in this form, therefore, the same current will produce different deflections at different parts of the earth; of course, also, the neighbourhood of magnets or currents, or of masses of iron, will disturb the action: in some cases this is remedied by using permanent magnets to control the needle, in place of the earth's magnetism, of such power as to render other agencies of small effect. In other forms a mechanical resistance is employed, such as the torsion of a wire or fibre, or a bifilar suspension. In vertical galvanometers the resistance is the extra weight of the lower parts of the system.

344. STAND FOR GALVANOMETERS.—There is often some trouble in arranging instruments so that the needle stands directly upon the N. S. or zero line, and many galvanometers turn on an axis for this purpose. A revolving stand is, however, a great convenience for a variety of purposes. The base should be of seasoned wood, fitted with three levelling screws, and a vertical axis rising from its centre. Upon this revolves a smaller disc, with set-screws or springs at opposite ends of one diameter, to hold it steady when adjusted. By marking the edge of one of the discs in degrees of a circle, and attaching a pointer or vernier to the other, this stand converts any form of galvanometer into a sine galvanometer.

345. GENERAL PRINCIPLES.—When a magnet is suspended simply in the magnetic field of the earth, it stands magnetic North and South, which is called the zero line.

When the magnetic field of the earth is neutralized by other magnetic agents, or, as in perfectly astatic needles, the magnet has no directive influence, it then, under the influence of any electric current, places itself in the line of the field due to this current; that is, if the wire be placed in the magnetic zero line, the needle places itself at right angles, or at 90° of deflection.

When an ordinary single needle is placed at the centre of a current moving in the plane of the magnetic meridian, this needle is deflected to a certain degree dependent upon the strength of the current. In this position it is influenced by *two equal and opposite forces*, the valuation of either one of which values the other. Of these two forces one is known—the action of the earth's magnetic field upon the needle, and, if we express this force in some definite system, we have the measure of the galvanic current, which, in the given circumstances, exactly balances it.

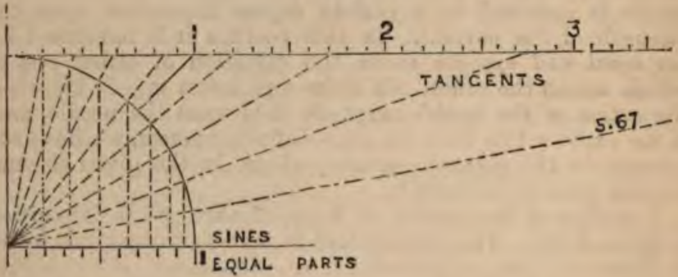
The effect of the number of turns of wire and their position is shown § 357. This is explained in text-books by a vast array of formulæ; but unfortunately, as with many other highly wrought mathematical formulæ, they too often tend to hide away out of sight the real principle. The student should clearly realize that all the theories and laws set forth as to the influence of distance of the wire from the needle resolve themselves into this one point, the development of the magnetic field due to the currents in the wires.

The influences of the two forces are, according to known laws, proportional to the sines of their relative angles, that is to say, considering the one angle of deflection alone, the pull of the earth's field upon the needle is proportional to the sine of the angle of deflection, while the pull of the current is equal to the cosine of the same angle, and the relations of these different trigonometrical measures are defined by the tangent of the angle.

346. Fig. 40 will assist readers unfamiliar with trigonometry to comprehend terms often met with. The vertical line is the perpendicular of a right-angled triangle, of which the base is the upper horizontal line of *tangents;* the other two angles are formed by the *hypothenuse*, which is the line from the centre passing through the arc of the circle at the degree which defines *the angle*, to which all the measures and terms relate. Extended as shown in dotted lines to the tangent line, the hypothenuse of the right-angled triangle formed is called the secant. The

dimensions of the *angle* relate only to the opening of the two lines, that is to say, to the arc of a circle which they inclose, but may be measured by any other of the essential lines, provided a unit or known length is taken for one of these lines, which then governs the size of the right-angled triangle formed. The unit is called the *radius*, as from that the circle is struck: radius then is 1; in the figure one inch. The radial dotted lines inclose areas of 10° each from the perpendicular radius, and lines drawn from the end of the radius to where the lines cut the circle are the chords of the arc. The horizontal line is that of *tangents*, defined for each angle by the prolongation of the secondary radius inclosing it, the hypothenuse or *secant of the angle;* the unit tangent, that equal to the radius, or 1, is the tangent of 45° (shown by a line from 1 on the scale, to the arc). The *sine* of an angle is a line drawn from the intersection of the secant to the radius, parallel with the tangent line; its unit length, equal to radius, 1, is the sine of 90°, and the lower line is divided to correspond with the actual sines, not shown themselves, but defined by the vertical dotted lines, which are the *cosines*, or sines of the complementary angle. The advantage of the tangent scale is that it is one of *equal parts*. Scales of natural, i.e. proportional sines and tangents are to be found in most engineering pocket-books; and logarithmic values, which are necessary for many calculations, are furnished with the common logarithmic tables.

FIG. 49.



347. VALUES OF DEFLECTIONS.—Degrees or tangents of degrees are merely proportions, and we need a unit value to give them meaning. As the measurement of the deflective power of the current is obtained in terms of resistance exerted by the earth's magnetic field, this latter must be expressed in a definite value,

or unit, in order to obtain the value of the current. The earth being a magnet, its lines of force converging towards the magnetic poles, the intensity of its magnetism is greatest at these poles; but this magnetism has two actions, producing the *dip* or vertical deviation, and the horizontal direction, p. 95. This latter is used in compasses and galvanometers, and moves the needle in a horizontal plane, drawing it to the magnetic N. and S., or zero line, and would draw a single pole (were such a thing possible) along that line. It is usually written H in formulæ, and is strongest at the magnetic equator, where the natural position of the needle, or the resultant of the earth's force, is horizontal, weakening as the pole is approached where the horizontal action is absorbed in the vertical. The horizontal intensity is proportional to the square of the rates of oscillation of the needle at any place; but for full information on this subject, works treating of magnetism can be consulted. What is necessary to observe here is that any galvanometer whose *constant*, or current, value is measured at one place, will require a correction, when used at other places, proportional to the relative horizontal intensities of the two places.

348. *Horizontal Intensity.*—This is subject to changes (besides the irregular ones occurring during magnetic storms), but the value usually employed is that measured in 1865; expressed in the metre-gramme absolute units that value is 1·764: in the foot-grain system its value is 3·826. These are the values symbolized by H, and they mean that a free unit pole would, under the earth's magnetic influence, acquire those velocities in one second of time. The measurement of this value can be effected by means of a tangent galvanometer and a battery of which the E M F is known, by the formula

$$H = \frac{E\,2\,\pi\,n}{R\,.\,r\,\text{tang}\,\theta}$$

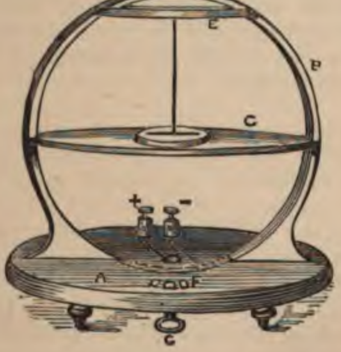
where π is the circumference, r the radius, n the number of turns, R the resistance, and θ the angle. See also § 148.

349. *Zero Line.*—The zero N. and S. line is itself not fixed, so that to make correct measurements the galvanometer needs to be placed in the actual zero line at the time of observation. There is a small annual variation of the mean position dependent on the season, and a larger daily one, both, therefore, due to the changing position of the sun in relation to the place of observation, and probably caused by thermo-electric currents set up by the motion of the earth under the sun. According to

observations made in Paris by Cassini, the amplitude of these diurnal motions is 13 to 15 minutes of arc, from April to September, and from 8 to 10 from October to March. During the night the needle is nearly at rest; at sunrise the north pole moves westerly to a maximum between noon and 3 p.m., when it returns to the east, in both cases, as though the south pole were attracted towards the sun: these variations increase as the magnetic latitude increases. The needle occupies the mean zero position about 10 a.m. and 7 p.m.

350. THE TANGENT GALVANOMETER.—It is best to commence the study of galvanometers with an instrument theoretically perfect, rather than with those which are merely simple in form. The tangent galvanometer is one in which the foregoing principles are carried out; that is to say, one in which the magnetic field, generated by the current, is so large that the motion of the magnetic needle within it does not materially change its relations to that field. Therefore the essence of a tangent galvanometer is that the diameter of the wire coil carrying the current shall be *at least* 12 times the length of the needle.

F.G. 41.



351. *Construction.*—The best construction I have been able to devise is shown in Fig. 41. An elliptical board A is supported by three levelling-screws, two visible and one beyond the binding-screws. The ring of wire is let into this table and supported by two blocks of wood; across its middle (a little below the centre) a table C is secured, which carries the dial, surrounded by a rim in which a glass cover can be placed. The needle may be supported by a steel point in the centre of the dial, or suspended by a silk fibre from the middle of the small piece of wood or brass E, also secured to the ring; this can be best adjusted to centrality, so as to compensate for any slight want of true levelling, by an apparatus similar to the mechanical stage of a microscope. I have shown an instrument of three *circuits,* thrown into action by a commutator F, G working under *the stand.* The end of the circuit, i. e. the largest conductor,

is soldered to binding-screw −, the other ends are taken to three studs F, the wires being slightly let into the wood; a screw-stud connected to binding-screw + carries the spring which completes either circuit as needed.

352. *Connections.*—All these should be kept as close as possible, to neutralize each other's influence on the needle. If they are some distance apart, especially in the plane of the circle, part of its action is neutralized by the current in them; the conductors will also act irregularly on the needle, according to the side to which it is deflected, and destroy the true tangential values of the deflections. It must always be remembered that conducting wires and connections form an integral part of every electric system; we cannot confine the action just to those wires which we call the instrument proper.

353. *Details of Circuits.*—Such a three-circuit instrument may be constructed by forming a ring of paper upon a disc of wood cut in two and temporarily secured to the table C; this can then be mounted on a stand for convenience of winding. Lay on forty-five turns of the finest wire to be used, say No. 20, then four of No. 16, then a complete circle of thickish copper sheet; next five turns of No. 16 and forty-five of No. 20 will complete the wires. The ends of these, coming out at the lowest point of the ring, must be so connected that the current enters by the single ring and goes to the 1 stud, or continues through the nine turns of No. 16, and then, in like manner, to stud 2 and to the ninety turns of No. 20, always, of course, in the same direction around the ring, and, finally, to 3 stud. The commutator puts into the circuit 1, 10, or 100 turns of wire, and by the arrangement of winding, these being practically all at the same distance from the needle, one value will apply to all the circuits, dividing the current value by 10 or 100.

354. *Value of Deflections.*—The actual deflection any particular tangent galvanometer will produce with a given current, say the unit current of 1 ampère or chemic, will depend directly upon the number of turns, and inversely upon the distance of the rings of wire from the centre; this relation is derivable from the following law:—

A current of unit strength placed once round the circumference of a circle of unit radius, in the plane of the magnetic meridian, will cause a short magnet, suspended at the centre of the circle, to be deflected through an angle whose tangent is 6·2832, divided by the absolute horizontal intensity of the earth's magnetic force at the time and place of observation.

For any diameter, calling H the earth's horizontal intensity, r the *radius of the coil, d* its diameter, L length of wire in the coil, all in metres, n the number of turns, θ the angle of deflection, and C the current strength in absolute (metre-gramme-second) units, we have:—

$$C = H\frac{r^2}{L} \text{ tang } \theta^\circ; \text{ or } C = \frac{H}{12{\cdot}566} \times \frac{d}{n} \text{ tang } \theta.$$

The result will be expressed in metre-gramme-second units, and multiplied by 100 will give the current in ampères.

The value may be ascertained practically by passing current from a constant battery through a copper or silver voltameter for an exactly noted time, taking care that it is perfectly steady, and observing the deflection very carefully. This will give the value of that deflection in ampères as explained, § 383.

All these valuations imply that there is no disturbing action, such as currents or masses of iron, and that the observer has no knives or keys in his pockets.

Deflections exceeding 60° are very unreliable, because of the rapid growth of the tangential scale. Even at 50° a single degree means three times as much current as at 10°, four times at 60°, and forty times at 80°, so that the smallest error in reading becomes of great importance at these large angles.

355. *Other constructions.*—In order to obviate the small errors of the single ring system, when the ring is not very large, two rings are occasionally employed, in order that the needle, being suspended between them, the errors due to its motion may compensate each other. This, however, tends to introduce another error affecting the smaller deflections, and therefore of more consequence than the other, which tells mainly upon the comparatively useless large deflections. It is also stated that the deflections are accurate if the wire is wound upon a section of a cone, of which the needle forms the apex, at a distance of one-fourth of the diameter of the nearest coil of wire. In neither of these forms is there any defined law of construction, and the chief advantage of the double ring form is that the resistance may be lower by dividing the current, and the range of power regulated by the distance of the rings. It would seem that these forms are more expensive and difficult of construction than the simple ring, and that they have small advantage over it, if the ring itself is made of a width at least equal to the length of the needle and of sufficient diameter.

356. THE SINE GALVANOMETER.—In § 345 it is shown that the

pull of the earth varies as the sine of the angle of deflection from zero, its full power being exerted at 90°. The pull of the current is greatest at 0°. Hence in galvanometers with wires fixed in position, the deflective power weakens as the resistance to it increases, and the influence of equal increments of current is rapidly reduced, as seen § 354. In the sine galvanometer the needle is always in the line of utmost action of the current, because the wire follows the needle in its deflection. Two results follow: 1, The current always exerts its full power; and, 2, as the needle is always in the middle of the magnetic field of the wire, any construction or arrangement of the wires is available, and any horizontal galvanometer may be converted into a sine galvanometer by placing it on a stand movable on its centre and fitted with an index traversing a graduated scale, as described § 344. All that is required is to place a stop or a small weight on each side of one end of the indicator, to limit the motion to a degree or two. When current passes, the needle moves against the stop; then the instrument is moved gradually on its axis till the needle resumes the normal position on the zero line. A reading is now taken of the degrees of arc through which the instrument has been turned, and the current is proportional to the sine of this reading. A measure of the value, in any unit, of one deflection then gives the values of all readings from a table of sines, but, of course, variable with the strength of the earth's magnetism, and other influences, as with the tangent galvanometer. Long and heavy needles are best with these instruments, which are, however, little used now.

357. ORDINARY GALVANOMETERS.—Most galvanometers are composed of two flat coils of wire placed side by side, with a space between them to allow the needle to enter the chamber formed by the interior of the coils. The power of the instrument depends upon the strength of the magnetic field produced by the wire with any given current; that is to say, upon the number of turns of wire which are effective, and their degree of effectiveness. As to this, it might be supposed that the position of greatest influence of the current is on the zero line, and close to the needle. But this is not the case. I constructed an experimental instrument in which the conductor could be exchanged so as to constitute a single turn of wire at vertical distances of $\frac{1}{4}$, $\frac{1}{2}$, 1, and 2 inches from the needle, and movable horizontally to any distance from the zero line. I passed uniform currents of 1 chemic and 5·4 chemics, and noted the deflections through a large range of positions. For experimental purposes, I assumed that the deflections were of tangential

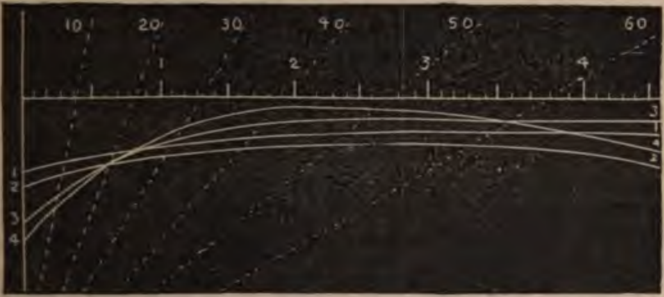
values, and constructed curves of action; these showed that the power of the current over the needle increases as it follows the deflection. As the wire moved out from zero, the deflection increased, as though the needle were being pushed out, until the wire was nearly over the pole of the needle: it was evident that the wire is ineffective beyond a certain horizontal distance, which is smaller the nearer the wire is to the needle. The reason is obvious if we consider the magnetic fields generated. It is evident that the double coils constitute, not one, but two fields overlapping each other, and the strongest part of each field is in the vertical plane of the middle of the coil. The consequence is that on the middle line of the two fields they have a weaker action upon the pole of the needle than they have as the deflection increases. The action of each point of the wire upon the pole varies, in fact, as the square of its distance; if, then, we consider the action at the zero line as representing distance 1, the effect of the two coils will be 1 + 1 = 2; but if the position is such as to halve one distance and double the other, we have the sum of the actions 4 + ·25 = 4·25, double the first power. Of course this is only a very rough mode of reckoning what could only be exactly represented by an elaborate array of figures, such as are given in some text books, to calculate the proper form to give the wire space in Thomson's reflecting galvanometers. As the vertical distance of the wire increases, the overlapping of the two fields increases, and the action becomes more equal, till at a considerable vertical distance, the wire gives a curve approximating to the straight, or tangential line.

358. It is evident that no simple law can give the value of the deflections of such instruments, because the position of every turn of wire has its effect upon the field; but a line can be ascertained by experiment, which fulfils the function of the line of tangents in the more perfect form, this line being a curve varying with the positions of the wires. This (which no one else has described, to my knowledge) is the plan I devised for calibrating galvanometers. By placing the instrument in circuit with a tangent galvanometer graduated in ampères, I obtain a series of corresponding deflections which I transfer as radial lines upon a paper mounted upon a table having a large quadrant drawn upon it, and fitted with an arm working on a centre pin. Knowing approximately what the curve will be, I run a pair of compasses, open to a suitable space, over these lines, and thus obtain a curved line which can then be divided into equal parts, and which acts as a scale, several feet in length, from which, by means of the radial bar, the actual dial of the galvanometer

is easily and correctly drawn. Such a set of curves is shown in Fig. 42.

359. One object I have aimed at in galvanometers is to so construct them that the action of any of the horizontal sections should be equal, and such that it should vary as the number of turns of wire occupying that section. This can only be really accomplished on condition that there is no central opening, but it can be approached if the wire in the inner layers is extended so far into the ineffective space as to compensate for the greater power of the turns near the middle.

FIG. 42.



Of course this diminishes the actual power of the instrument: but the object is not to use the wire so as to produce the utmost effect, but to obtain a particular result. In this way I have produced circuits of 1, 10, 100, 1000 turns, which, with those numbers of ohms in circuit, would each produce a deflection of 34° with a current from the same Daniell cell.

Fig. 42 shows a set of graduation curves obtained for an instrument having four circuits, consisting of

No. 4,	..	900	turns	No. 26	cotton-covered wire
3,	..	90	,,	18	,, ,,
2,	..	9	,,	18	,, doubled
1,	..	1	,,		sheet copper.

The whole being continuous, this gives four circuits of 1, 10, 100, 1000 turns, so arranged as to have approximately equal actions, and give reading of current from 15 ampères to ·0001. In this instrument there was a wide opening in the middle, and the effect is shown in Curve 4, which is that of the circuit closest to the needle. Where the curve rises, the current has least *power. The curve shows* also by its rapid fall beyond 50°

that the wire does not extend far enough from the needle to equalize the field. Curve 1 shows the effect of increased vertical distance in doing away with the effect of the middle opening, and also in utilizing the outer portion of the plate of metal filling the space devoted to that circuit. It shows clearly that at a further distance the curve would flatten down into the simple tangent line, Fig 40, which is the scale of equal parts shown Fig. 42, indicating ampères on Curve 1, and the corresponding decimal submultiples upon the other curves. It should be understood that an unsatisfactory instrument is here selected, because of the lessons it teaches, and because, on this small scale, good curves would run into each other too much.

I have made instruments on this plan which would measure currents from that of a large Grove cell, say 18 ampères, direct and without shunts, down to that passing through a vacuum tube.

360. It is remarkable that no text-books explain that galvanometers can show the resistance of the circuit as well as the current, provided the electromotive force is known. I discovered and patented this.

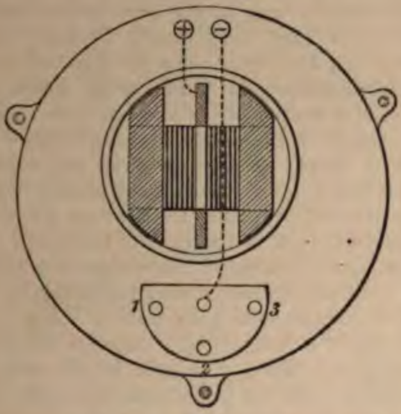
As current and resistance are linked together by a defined law, they being inverse to each other, as $\frac{E}{R} = C$, and $\frac{E}{C} = R$, so also, as in a tangent galvanometer, C varies as *the tangent of the angle*, it follows that the resistance varies as the *co-tangent of the angle*. Therefore, as the line of graduation for current originates at the zero line, or at 0°, so also a true line of graduation for resistance originates at 90°, the graduation of that line depending on the E M F employed: the Daniell cell is the only one suitable for this purpose.

361. For convenience of amateurs who may wish to construct an instrument of this kind, I describe a simple form with three circuits, which will answer many purposes.

Fig. 43 represents a stand with three levelling screws; on it are fixed the coils of the galvanometer and a commutator for throwing different lengths of wire into circuit. The coils may be made in one frame on a flat copper tube, or as is usually done, in two parts, one on each side of the needle; the sides of the frames are secured to the stand either by brackets, or if made of wood, by brass screws passing up through the stand. Even if made separate, the two sides of the coils should be mounted together on one mandrel for winding, so as to distribute the wires equally between the two. The chamber within the *coils, in* which the magnet plays, should be 2 inches long and ½ *inch deep, and* the frame made 3½ inches long and 1¾ inch high, so as to form channels or spaces in which the wire will lie, ¾ inch wide, and the same in depth all round the central chamber.

The laying on of the wire begins in the middle, and each end must complete an exact turn at the middle, or the indications

FIG. 43.



would be inaccurate. First lay on 90 turns of No. 20 cotton-covered copper wire, leaving 6 inches out for connection; 45 turns on each side will bring the coils back to the middle line. Solder the end of the No. 20 (at the exact turn) to a double length of No. 18, leaving 6 inches of these out for the connection, and lay on nine turns of one of these wires in each channel, so as to divide the current between them. Finish with a strip of copper ¾ inch wide joined to the 18 wire, at the exact spot completing a turn, and leave the ends of the wire out for connection; make one turn of the strip and bring out, on each side, a wire soldered to it, for the commencement of the coils. This will give three circuits with decimal ratios (nearly) to each other. The wire ends are to be carried through the stand, and led to the required points. The two outside ends are taken as one (dividing the current) to the binding screw +; the next pair of No. 18 representing one turn round the needle, are taken to 1 of the commutator; the next pair are taken to 2, giving 10 turns; the first end of No. 20 wire which completes 100 turns goes to 3.

362. The commutator is similar to the one used frequently on medical *coils, a central pillar* connected to binding screw – and

a spring from it traversing over the numbered studs. For some reasons it is better to use mercury cups thus: a block of hard wood an inch thick has central and radial holes $\frac{3}{4}$ inch deep by $\frac{1}{4}$ inch bored in it, and when fixed on a stand, holes are bored through just large enough to pass a No. 12 copper wire, on which a head has been hammered up. These heads are well amalgamated, and a piece of wire bent twice at right angles passes from the central cup to the one desired to be used; the resistances are thus kept very small, so that when used for measuring batteries, &c., they may be ignored in many cases. A convenient commutator is made with brass screws fixed near the edge of the under side of the base, to which the wires are soldered, a considerable lump of solder run over them, and all brought to a level; a spring with a projecting handle traverses these screws, being itself held at any convenient part of the middle line of the base by a brass screw and a large bearing surface connected to the proper terminal.

The needle is $1\frac{7}{8}$ inch long, of four strips of watch-spring, and may be fitted with an indicator and mounted in either of the ways described § 305, so as to play within the central space; if mounted on a point a long needle may be fixed in a piece of brass and screwed up through a hole in the stand and in the middle of the coils, with its point somewhat above the level of the frame. On the frame is secured a dial of cardboard, with an opening in the middle to pass the needle through, and a glass cover should go over all.

363. The graduation can be effected as before described, but the following values will approximate to the readings:—

Chemics.	Degrees.	Chemics.	Degrees.	Chemics.	Degrees.	Chemics.	Degrees.
1	11·3	5	43	9	58	30	79
2	22	6	47·5	10	60	50	83·5
3	31	7	52	15	69	100	86·5
4	38	8	55·5	20	73		

These figures represent the indications on No. 1 circuit: when No. 2 is employed they are to be divided by 10, and by 100 for No. 3. By using finer wires more circuits may be used, but the size of the frame must not be increased, and the whole space must be filled, or the ratios will not hold good.

364. VERTICAL GALVANOMETERS.—For many purposes the needle works in a vertical plane, mounted on a central pivot, in which case the needle is double, one working inside a coil, the other, with its poles reversed, working outside. Such an *instrument—which* is, in fact, the needle telegraph instrument —*has its advantages* in instantaneous action, as the needle does

not vibrate as in the horizontal form, and ready visibility from a distance, which specially adapts them for use as mere indicators; they can also be placed in any position, and are not much disturbed by neighbouring currents or magnets, but their indications are not to be trusted, as explained § 343. They are much used in practical operations, such as testing wires, for their portability and general handiness, and in such cases are usually made with a double wire so as to be employed as a differential galvanometer. The construction is the same as that of horizontal instruments, the difference being in the mode of suspending the needles and the mounting in a case.

The sensitiveness may be increased if the axis of the needles is pointed at the back so as to work in a cup, by inclining the instrument, and so diminishing the height through which the weight has to be lifted for a given deflection.

365. DIFFERENTIAL GALVANOMETERS.—These may be made of any form. They consist of two similar wires side by side throughout, but carefully insulated from each other: they must have equal influence upon the needle, and also equal resistance. To secure the first, care must be taken that the wires are equally tightly laid, so that one has no greater length at any part than another. They should make a half twist at each layer to bring them alternately the nearest to the needle; if this precaution is not taken, and a needle suspended by a fibre is used, the needle is apt to be drawn bodily towards one side, and to be deflected in opposite directions according to the side it is drawn to, in which case no reliance can be placed upon it, as the least change of level will cause it to turn either way with the same currents. For this reason, probably, differential galvanometers are usually made with pivoted needles, thus lowering their sensitiveness. To test the equality of action the two coils are to be connected at the one end, so that the current goes by one and returns by the other; no deflection should be produced, however strong the current. If any is shown, it may be corrected by adding one or more turns of one wire, or if this gives over-correction, by unlaying part of the wire having least influence and laying it again somewhat loosely so as to lengthen it. The equality of resistance may then be tested by connecting up the instrument so as to divide a current between its two coils with reverse action, and adding wire outside the coils to the one having most effect until they exactly balance; or the resistances may be equalized by means of the bridge.

A differential galvanometer may be employed as a single circuit *of alterable resistance* and powers, as one circuit may be used alone, or the two coupled as one, reducing the resistance to half of that of a single circuit: or they may be used in series with double the resistance but double the action on the needle, each of which arrangements suits varied conditions of resistance in the rest of the circuit; such an instrument is therefore of use with the Wheatstone bridge.

366. A good differential galvanometer enables resistances as well as currents to be compared on principles similar to those explained, § 399. If the two coils are exactly equal, currents may be compared by passing them in opposite directions. Two resistances may be compared by putting one in each circuit, and then connecting to one battery so as to divide the current between them: if one is a resistance to be measured and the other a resistance instrument, by altering the latter till there is no effect upon the needle it measures the first resistance. Multiplying ratios are given to the instrument by means of shunts, § 369. These are provided to one or both the circuits in such way as to open other paths to the current and allow $\frac{1}{10}$ or $\frac{1}{100}$ of it only to pass the coils; then the actual resistance inserted in the other circuit has to be multiplied by 10 or 100 to give the resistance which it balances.

In using these instruments, when the resistance to be measured is equal to or greater than that of one of the wires, the resistance and rheostat should be inserted in the circuit as described: but if the resistance is less, it is better to couple the two circuits so as to neutralize each other, and to use the rheostat and resistance to be measured, as shunts, one for each circuit.

367. Thomson's Reflector.—This valuable instrument is so purely technical in its uses, that a full description is hardly required here, especially as it is rarely likely to be made by any one not familiar with it. It is usually constructed upon a vertical brass plate about $\frac{1}{4}$ inch thick, securely mounted by pillars upon an ebonite stand. In the plate and upon each side of it are turned circular recesses, leaving a thickness of less than $\frac{1}{8}$, the centre of which is also entirely cut away, as well as a vertical space in which hangs the needle system. Four reels, about $\frac{3}{4}$ inch wide and of 2 to $2\frac{1}{2}$ inches diameter, of brass or ebonite, with a central tube of $\frac{1}{2}$ inch bore, contain the wire, and are made to fit into the recesses of the plate and held there either by large headed screws or by turning small catches so as to grip the edge of the reels. The coils are connected in pairs, leaving four ends which are connected to binding-screws, so that if the coils are exactly alike and carefully adjusted they *may be* used differentially, or at any rate be connected variously *as described* § 365. In some cases also there are double wires

used to make the instrument a truly differential one. According to the purposes desired, different sized wires are used; but fine wire (No. 40) is generally used, and a resistance of 8000 or 10,000 ohms laid on.

The needle system consists of two pieces of watch-spring $\frac{3}{8}$ inch long, cemented upon an aluminium wire so as to occupy the middle of the coil tubes; on the upper needle is also cemented a mirror made of a microscopic cover silvered and inclined so as to reflect a little upwards, and a slip of mica is fixed across the lower needle so as to act as a damping vane, and limit the play of the needle. At the top of the supporting plate, and in a hole drilled exactly down the central line, is a sliding wire with a hole in its lower end to which is hooked a silk fibre attached to the aluminium rod of the needles; this fibre should have as much length as possible given it, and by slightly raising or lowering the rod the needles can be properly arranged for work, or lowered so as to take their weight off the fibre when moved about; this needle system should weigh altogether only 3 or 4 grains. The mirror is sometimes made somewhat concave, so as to concentrate the light at a given focus.

The instrument is covered with a cylinder of glass with a flat brass top, from the middle of which rises a brass rod fitted with a tangent screw to move it gently round. The rod carries a sliding tube on which is fixed a curved magnet, by altering the position of which the needle is controlled, as to delicacy by the height of the magnet, and as to position by the line in which the magnet is placed, so as to supersede the small directive action of the earth upon the nearly astatic needle system, which is powerfully controlled by this magnet owing to its greater nearness to the upper needle.

368. *The index* is the beam of light reflected by the mirror from a lamp placed behind a screen 2 or more feet distant: usually a narrow slit is provided, which thus sends back a narrow line of light: it is much better to use a $\frac{1}{2}$ inch circular opening with a vertical wire (which should be a dead black) stretched across it; this reflects a black line crossing the graduation, surrounded with light enough to enable the graduation to be observed. The light is improved also by being placed some distance back, with a reflector and concentrating lens adapted to the distance of the mirror, so as to get a bright spot which does not require so much darkening of the operating room.

The screen has upon it a scale of equal parts mounted on a slide for *adjustment, and the* whole is to be so arranged that the indicating line or spot is upon the zero line, and is equally deflected to either side with reversed equal currents. The best screen is one of glass made translucent by grinding or by means of suitable varnish, upon which the scale is engraved. This form of scale is placed between the observer and the instrument, and should have a frame work of black cloth around to throw it up; it can then be used in diffused daylight.

The deflections within the small limit of play allowed are proportional to the tangent of the angle of deflection, and, consequently, to a straight line divided into equal parts forming the scale: an absolute value can be given to the deflections, as with the tangent galvanometer, by ascertaining the value of one deflection; but this value will only hold for the same distance of the scale, which distance can therefore be adjusted so as to bring the unit deflection of, say 100 parts, to some decimal submultiple of the ampère.

369. *A shunt* is always provided with the instrument so as to send $\frac{1}{1000}$, $\frac{1}{100}$, $\frac{1}{10}$, or all the currents into the coils: by using these as accuracy of measurement is approached, observations can be made without throwing the needle about too violently. The instrument must be absolutely steady, and therefore fixed upon a brick pillar, or upon a shelf fixed on a solid wall, otherwise the spot of light is always dancing about, and it is impossible to make any useful observations.

370. Permanent magnets may be attached to any form of galvanometer, as described § 367, as is done with the Post Office tangent galvanometers, and they may be adjusted by putting a good Daniell cell in circuit and a total resistance of 1·07 ohms or the proper multiple, and shifting the magnet until the instrument reads the corresponding unit current.

371. *Control Magnets* are used in other forms, in substitution for the earth's field: they are more powerful, which makes the instrument more sensitive, and they are less subject to disturbance, a great advantage in the neighbourhood of dynamo machines; but though it is said by those concerned that they retain their charge, that is not an accepted belief, see § 146. They have been used in England by Professors Ayrton and Perry, and in France by M. d'Arsonval. Any form of coils, horizontal or vertical, may be used; but the needles should be small, and arranged in the centre of the field of the permanent magnet. In some instruments the control magnet is constituted by the current itself: in this case the core should attain its maximum magnetism with a small current; a wire of very pure, *soft* iron as long as can conveniently form a horse-shoe within the instrument, may be wound with a layer of wire, acting

as a shunt to the coils: the size and length of this wire will vary, of course, according to the magnitude of the currents intended to be measured.

When permanent magnets form part of a measuring instrument, they should be made of the best magnetic steel, magnetized to saturation, and then submitted to moderate vibrations, such as tapping with a piece of wood, and dipped in boiling water a few times with some days' interval; this will bring them into the practically permanent condition they are likely to retain, unless subjected to magnetic stresses.

372. *A solenoid, with soft iron core* to be drawn into it, makes a simple and convenient meter, best suited to large currents, and many forms can be devised. The core can be suspended from a spring balance, and proper graduation be effected as with other instruments; or it can be counterprised and slung over a pulley fitted with an index arm, so as to cause a small vertical motion to move the index over a large space, and thus give ready subdivision.

373. A good plan, not readily adopted by amateurs, is to put the iron into the long bulb of a hydrometer, which is placed in a closed tube containing a suitable liquid: this tube then forms the core of the coil, and the indications are given by the length of the hydrometer stem drawn into the liquid, or by a pointer attached to it and an external scale. The iron may be a bundle of wires, and it should be conical in form, largest at the top, so as to prolong the pull of the current and equalize the divisions of the scale, by the growing mass of iron acted upon compensating the diminishing pull of the coil.

374. BALLISTIC GALVANOMETERS are of any type, but provided with a needle having so much inertia that it swings slowly, and does not complete its first swing till some time after the ending of the momentary currents that are used for measuring. A weight is often attached to the needle for this purpose, but there should be as little air resistance to motion as possible. They are used for measuring the discharge of a condenser, or the induced current at break of circuit, and the indications are proportional to the sine of half the angle of the first swing.

375. VOLTMETERS are simply galvanometers of high resistance inserted as shunts in the circuit they are intended to measure. They are based upon Ohm's law and the proportions of E M F and current in a fixed circuit; they require correction for temperature if accuracy is desired; they are the more to be relied upon the higher their *resistance*, as they should not alter the conditions *of the total circuit* appreciably, as they do when

their own resistance does not very greatly exceed that of the circuit they are used with.

376. GERMAN SILVER WIRE.—For purposes requiring a high and constant resistance, galvanometers are best made of German silver wire, owing to its small variation of resistance by temperature. But this only relates to external temperature: as to the heating effects of the current itself, German silver wire is worse than copper, and therefore variations in the ratio of shunts will be greater with it than with copper. German silver increases its resistance only about $\frac{1}{9}$ as much as copper, but a wire of the same size would have 12 times the resistance, and therefore collect in it 12 times as much heat from the passing current. German silver wire is most useful in voltameters, for which the new alloy called platinoid is also useful. But for all ordinary purposes wire of the very highest conductivity should be employed.

377. RESISTANCE OF GALVANOMETERS.—It is usually stated that the resistance should equal that of all the rest of the circuit. This, like the similar statement as to batteries, is apt to mislead. *Resistance as such has nothing to do with the matter;* it is always a disadvantage, except for special purposes. But resistance carries with it the number of turns of wire, and consequent power; therefore in a given space for coils of wire, that space should be occupied by stout wire in a circuit of small resistance, because fine wire would introduce a useless resistance; with a circuit of large resistance fine wire must be used in order to get sufficient effect. But a fine wire instrument can be utilized by means of shunts, which divert part of the current from them, reduce their sensitiveness and also the resistance of the circuit.

378. MEASUREMENT BY CHEMICAL ACTION.—Faraday proved that when an electric current passes through a liquid (whether fused or in solution), the substance is separated into two parts, one of which appears at the positive, the other at the negative pole. As this chemical action is proportional to the "quantity" of electricity circulating, any such action can be used to measure the current which effects it. The process commonly used is the decomposition of dilute sulphuric acid, usually termed the decomposition of water, because the constituent gases of water, H_2O, are set free.

379. VOLTAMETERS.—Instruments for this mode of measurement are thus named. Their form is subject to infinite variation, for all the essentials are the two conductors, an outlet for the gases, and a means of measuring them, either separately or together. The drawback to these instruments is that they not

only present a considerable resistance, but create a *counter electromotive* force, which in the case of gases, needs a force equal to one Grove's cell to be employed solely in working the voltameter. The electrical *resistance* proper is a matter of size of plates, which must be proportioned to the current they are intended to pass; this cannot be controlled by shunts, because of the counter E M F which acts as a variable resistance in the cell. For general use the plates should be as large as is convenient; platinum is used because it is not acted on; carbon would answer, but for its tendency to absorb the gases; and the action noticed § 317 unfits it for use as anode with currents of large density.

380. A simple form may be made from an ordinary wide-mouthed bottle. Two plates of platinum with wires attached are mounted on the cork with binding screws outside; in the middle of the cork a glass tube is fitted to carry off the gas by means of a flexible tube to a measuring jar: the end of this tube should project a little within from the surface of the cork and be cut off slanting so as to resist the ingress of moisture, and the cork should be boiled in melted paraffin.

If it is desired to collect the two gases separately, the cork should be fitted with two glass tubes as large as it will admit, and going nearly to the bottom of the bottle. The tubes should be left open at the bottom, and closed at the top with a cork fitted as before, with a gas leading tube and a strip of platinum: these giving off each its proper gas within the tube, completing the liquid circuit by the open ends dipping in the liquid.

For experiments with very small currents, as with induction coils, large surfaces are objectionable, as so much gas is retained by them and in the liquid: for such occasions a wire inclosed in a glass tube melted to it and exposing only the end, is used. These may be fixed in tubes and used as just described, or both may be passed through a cork in the neck of a small bottle with its bottom cut off, in which two small test tubes can be inverted over the conductors, so as to make a model of one of the common forms of voltameter.

381. As before stated, these instruments are objectionable on account of their great resistance. It is, however, quite possible to have a voltameter which shall not give resistance, but shall help the current. A Smee cell is to all intents a voltameter, if we collect the gas given off, and ascertain how much of it is due to local action; the mode of effecting this is described § 198: a cell for this purpose should be large enough to transmit the current freely, and its *outlet should* be closed when not in use so as *to keep the liquid charged* with gas.

382. We have now to learn what the measure of gas given off teaches; a point which electrical writers usually fail to clear up, because they deal only with the actual measure itself, and base upon it arbitrary units, as, for instance, Jacobi's unit of current, that which in one minute generates one cubic centimetre of mixed gases at 0° C. and 760 mm. barometer, or a cubic inch of gases.

But what we really want is to know what *measure* of gas corresponds to such a definite weight as furnishes the unit or "chemic" current; to value the indications of the voltameter as those of galvanometers are valued. By the system of weights the current is measured by the number of equivalents of any substance acted on, ascertained by dividing the total weight by the known equivalent weight. Now, the system of measure is still more simple, for any atom of a simple substance, or still more inclusive, every molecule of any substance, simple or compound (with a few exceptions), occupies in the gaseous state the same volume, no matter what its weight is. What we want is the relation between the equivalent weight and this molecular volume.

In water, H_2O, there are three atoms, all of equal volume; but as to weight, hydrogen being unity counts 2, and oxygen by its atomic weight 16, makes the molecule of water 18, which answers to two electric equivalents. Once we know then the measure or bulk of 1 grain of hydrogen, we know the weight of the same bulk of every other gas of known constitution.

The best mode of measuring gases is by the metric system reckoned at 0° C. temperature (freezing) and 760 mm. barometer (one atmosphere) correcting to actual temperature and pressure; but as exact accuracy is never attainable in this particular case, because part of the gases is absorbed, it is near enough to take the average condition at 60° Fahr. and 30 in. bar., at which, according to Miller, 1 grain of hydrogen occupies 46·73 cubic inches, which may be considered the unit or atomic volume.

Therefore, a chemic unit of quantity or current will give—

In the Smee voltameter, 46·73 cubic inches of hydrogen.

In the double voltameter, 46·73 cubic inches of hydrogen in one tube, and 23·37 of oxygen in the other.

In the single tube voltameter, 70·1 inches of mixed gases.

A tube of glass, such as the ordinary Mohr's alkalimeter, can easily be graduated to measure this off direct: 46·73 C.I. = 11797·45 fluid grains, therefore a tube containing 1179·8 grains divided decimally would contain one-tenth of a unit, and require *one* hour to fill by a chemic current from a Smee voltameter.

One cubic inch being 16·387 cub. centimetres, a coulomb *of electricity* or an ampere current for one second (chemic

$\times 5 \cdot 68 \div 36000$) represents cubic inch ·007373, or the "ampère hour," cubic inches 26·54 of hydrogen.

383. *The best voltameter* for many purposes is two plates of copper in a coppering solution; or a Daniell with flat plates, in place of a separate cell, will supply instead of absorbing energy. The weight of copper divided by 31·75 gives the number of units of electric action, and by the proportion of time occupied to the unit time of ten hours gives the current in chemics. In this way the value of one or more deflections of a galvanometer can be ascertained and its graduation effected, instead of by the formulæ given § 354.

For exact scientific purposes silver is used instead of copper, in a solution of nitrate of silver 15 or 20 parts in 100; and the proposed value of the ampère is a deposit of gramme 0·001118 of silver per second, which makes the ampèrage, or coulomb, equivalent to ·0000103518 in the hydrogen unit.

384. MEASUREMENT BY HEATING EFFECTS.—Whenever current passes through a wire it meets a certain resistance, in overcoming which equivalent energy is converted into heat, and the current, therefore, is capable of measurement by this heat. As an illustration of the erroneous nature of the older ideas, such as that heat is the two supposed electricities united, it must be understood that this conversion into heat of the energy of a galvanic current does not in the least reduce the "quantity" of the electricity; that is to say, a current arising from the consumption of one unit of zinc will deposit exactly the same quantity of copper, viz. one unit, whether it passes directly to the coppering cell, or whether a long fine wire, in which heat is developed, is also interposed in the circuit; the only difference will be that it will take longer about it.

385. Experiment, has, however, settled that—(1) In a wire of given resistance (ignoring the variation produced by the heat itself in the wire), equal currents always generate the same amount of heat. (2) With different currents the amount of heat varies, not in the ratio of the currents themselves, but in the ratio of the squares of the currents; thus, if a current of one unit produces in a given wire one heat unit, that is, sufficient to raise one pound of water one degree in temperature in a minute —then a current of two units will produce in the wire four such units of heat.

This is expressed mathematically $H = C^2Rt$; to give the heat developed in a given time any fixed value, a constant which is the heat equivalent of the current in a unit resistance for a unit time (such as one second) must be employed with the formula; for *which see § 426.*

In heating wires, it is to be remembered: (1) the same *current* will heat an inch or a mile of the same wire; the *length* heated in any given conditions is purely a question of resistance, and the force employed to pass the current; (2) to heat, equally, thicker wires, the *current* must be increased as the weight of wire per foot increases.

The arrangement of batteries to produce these two effects is number in series for the first, large cells for the second; and the resistances and electromotive forces must be arranged so as to produce the required current.

386. CALORIMETERS.—These little-used instruments are thermometers containing a platinum wire, through which the current passes. There are two kinds: (1) an air thermometer—a bulb with a fine graduated stem containing liquid; the platinum wire crosses the bulb; (2) a vessel containing a known weight of a non-conducting liquid, such as water or alcohol, the wire passes through this and a thermometer shows the temperature generated, which, with the specific heat of the liquid, gives the actual heat, expressed as a quantity. Thus, if a pound of water is used, each degree represents a unit of heat, and if the resistance of the wire is 1 ohm the calculations are very simple.

387. HEATING EFFECT UPON WIRES.—The formula in § 385 expresses the heat as quantity of energy; but another consideration is the temperature to which that heat can raise a particular wire. This depends upon the weight of metal in the wire, and the relation of the metal itself to heat, i.e. its specific heat. A general formula may be given, not reckoning, however, the heat lost by radiation and conduction.

C = Current in ampères.
R = Resistance of wire in ohms.
W = Weight of wire in grammes, see § 389 for grains.
s = Specific heat of metal.
H = Rise of temperature per second in degrees Centigrade.
·24065 = Calories equivalent to ampère-seconds, see § 426.

$$\text{Then } H = \frac{\cdot 24065,\ C^2,\ R.}{W.\ s.} \text{ or for copper, } \frac{66\ C^2,\ R}{W \text{ in grains}} = \text{deg. Fahr.}$$

Very full information will be found in Mr. W. H. Preece's papers to the Royal Society, Dec. 22, 1887, and April 19, 1888. The latter is in the 'Electrician', vol. xx, p. 718.

388. The *specific heat* of metals increases as they approach the *point of* fusion; therefore, platinum varies less than other *metals.*

The following are the average between 0° and 300° C.

	Specific heat.	Melting point. Deg. Centigrade.	Specific gravity.
Copper	·1013	1091	8·9
Iron	·1218	1805	7·8
Silver	·0611	1023	10 5
Platinum ..	·0355	2100	22·1
Zinc	·1015	412	6·9
Lead	·0314	620	11·4
Graphite ..	·2018	?	1·6

The *specific heat of alloys* is the mean of that of their components, and is ascertained by multiplying each specific heat by the percentage of the metal, and dividing the sum of the whole by 100. This only holds good at a distance from the melting points, which are usually not the mean of the constituents, but lower; and it is doubtful if it applies to those alloys which like German silver, differ in resistance greatly from that of the means.

389. The effects may be compared upon the system of English weights and units used in these pages, by taking, as the heat equivalent, the grain instead of the pound of water. Then the worth of the ampère current is 6·6855 such grain degrees Fahr., and that of the chemic $(5 \cdot 68)^2 = \cdot 20722$ per second, which figures may be used in the above formulæ to replace ·24065, the weight being expressed in grains, instead of grammes.

The length in feet of a wire weighing 1 grain per foot, which gives 1 ohm. resistance, is of course the weight in grains, and is for copper 4·845 and for platinum ·2828, and in these different lengths or weights equal *actual heat* is produced; but it will be found, when the specific heat is taken into account, that very different *temperatures* result.

If we multiply the unit heat of current 6·6855 by the reciprocal of the specific heat (that is 1 ÷ specific heat), we get the number of grains of the metal that unit heat would raise 1° Fahr., and dividing this by the length of the grain-foot-ohm. unit wire, we get the actual rise of temperature produced in that wire for an ampère current as 14·5° for copper and 730° for platinum; that is, a current which would only warm a grain-foot copper wire slightly would raise a similar platinum wire to a red heat.

390. In an experiment with such a platinum wire, I obtained the curious result that the loss and gain so balanced each other that the temperature maintained by the current closely corresponded with the calculated rise: but of course, this coincidence was *accidental, and only holds* for very fine wires.

HEAT OF WIRES.

Heat observed = Degrees Fahr.		Current in chemiks.	Calculated heat.
1. Ampère current		5·68	730
2. Faint red	1000 1300	7·	1109
3. Cherry red	1400 1800	8·	1473
4. Orange	2000 2200	9·5	2042
5. White	2350 2700	10·7	2585
6. Fused .. .. about	3700	12·6	2847

The last line of the experiments illustrates the fact that the breaking of a wire by the galvanic current is not due to pure fusion, but occurs at a lower temperature. The effect is partly analogous to the destructive effects of lightning. The fusing point is that at which the vibratory molecular motion of heat, § 39, just overcomes the attraction of cohesion; but, if electric transmission involves a motion or revolution of the molecules, it is obvious that this effect must be added to that of heat, and destroy the cohesion at a lower temperature.

391. COULOMB-METERS.—This is a new class of measuring instrument, called into existence by the distribution of electricity from central sources. They register the quantity of electricity passed through a circuit in a given time, acting in fact like the gas-meter. They are either chemical or mechanical.

The first electrical meter proposed was of the chemical order, and described in my own patent of 22nd November, 1878, though devised several years before, as a check upon the consumption of silver in electro-plating. It was based upon the deposit of metal, such as copper in sulphate of copper, and I said, "I use two plates of the metal, and cause each to become alternately the anode when the other plate has lost so much weight as represents the unit of current employed, under well understood laws; and I cause this change of direction in the current to be effected by the weight of metal passed from one plate to the other." I described the plates as "supported by spiral springs, or in any equivalent manner which will permit them to descend and rise according to their relative weights." I showed electro-magnets with a rocking armature between them, drawn over to either side, according to which magnet was in action, and these magnets set in action when the descent of one of the plates closed a contact fixed at the proper point, and said, "these points and the armature therefore constitute a *reversing commutator*, and other modes of effecting the purpose may be used:" then "the motion of the armature is caused to move a ratchet wheel one tooth, and by this means to record, in well-understood manner, the number of reversals of current, each of which represents a definite quantity of electricity passing." I described the use of shunts to send a definite part of the current into the cell, and said, "the essential point of this part of my invention is the production of motion in a set of wheels by the agency of plates of metal alternately dissolved and deposited on."

In later improvements, I employed the simple hydrostatic principle, using what was really a hydrometer connected to the circuit, with arrangements for carrying large currents, and enabling it to ring alarms, or cut the work out of circuit when complete.

392. On 27th October, 1880, Mr. Edison patented his Vebermeter, which differed from mine only by using plates at the ends of a balance arm, instead of on springs. The plan of measurement he has employed in practice is not properly a meter at all. He allows a small part of the current to pass through a pair of zinc plates in a zinc solution and the deposited plate is taken away and weighed at intervals, and the current computed.

393. But the chemical principle, though scientifically the most trustworthy measure of current, has various practical inconveniences which have prevented its adoption in practice, and various forms have been devised which depend on the mechanical work which can be done by magnetic actions, or by the heat generated in a wire by the current. Others involve clockwork, and integrate current and time. As there are some scores of patented instruments I cannot pretend to do more than describe the principles of some which have some special characteristics.

394. *Aron's* meter is the type of one class of meters: Messrs. Ayrton and Perry originated the system, which is the alteration of rate of a pendulum by the influence of an electromagnet or coil, energised by the current to be measured. Two exactly similar pendulums, connected each to its train of clockwork, actuate a differential gearing; giving it no motion as long as they swing together, but moving it forward if one moves faster than the other. In the meter for alternating currents one pendulum is a fine wire solenoid forming (with a resistance) a shunt to the circuit (§ 303), this swings within

another solenoid carrying the working current, so that, whenever a current is passing, the rate of the pendulum is increased by the pull of the solenoid added to that of the earth which acts upon both pendulums, these being adjusted to exact equality when current is not passing, in the usual manner, by a screw. The reading corresponds to the energy, but needs correction by a co-efficient, not always the same for largely differing currents, and which has to be determined for each instrument. This meter is largely used in Germany.

Messrs. Oulton and Edmondson have made a number of modifications which simplify the instrument, and they make it read in Board of Trade units.

395. *Chamberlain and Hookham's* may be taken as the type of another principle in which an electro-motor engine measures the current by the number of rotations set up in its armature. The retarding action in this meter is the currents produced by magnetism in a copper disc; in other meters these currents are used to generate motion; the disc carries the armature wire so that they revolve together between the poles of a magnet, and the axis drives the counting mechanism; mercury contacts complete the circuit of the armature instead of brushes, to diminish friction.

Professor Elihu Thompson has constructed a meter on the same principles, but different in arrangement of the parts.

396. *Ferranti's* meter utilizes the rotation which is produced in mercury when carrying a current in a magnetic field. The magnet is a cylindrical one, made of sheet iron magnetized by the current to be measured; this is carried from the centre of a trough containing mercury to the circumference, and thence through the coils of the magnet; thus the mercury lies in the magnetic field which the current crosses radially at all parts, and is therefore compelled to rotate in a direction dependent on the current, and therefore independent of that direction with an alternating current which changes the direction of the field and current together; a light float, in the mercury, is carried round with it, and moves an axis driving the register.

Lippman devised a meter in which the propulsion of mercury through capillary tubes should register the currents passing by a circulatory action, such as others obtain in other ways; the mercury is lifted out of one reservoir, and returned to it through a measuring apparatus.

397. *Taverner's* meter (which some have attributed to Elihu *Thompson*, who has done sufficient good work of his own) consists of a differential air thermometer, composed of two

glass bulbs joined by a bent tube containing mercury; each bulb contains a coil of wire connected alternately to the circuit. The air in expanding drives mercury into the other bulb, and causes the apparatus to tilt over on an axis till it closes a circuit reverser which sends the current to the other bulb. The effect is the same as in my instrument § 392, being due to the heat of the current instead of its chemical action; it therefore measures energy rather than current, and is applicable to alternating currents.

398. *Professor Forbes* has devised another very beautiful meter dependent on heat production; a circuit, in which heat is developed, is arranged below a system of vanes mounted on an axis driving the recorder. It is practically a windmill driven by the convection current of air produced by the heat in the wire.

399. *Messrs. Jehl & Ruff* also described a meter in which the heat developed in a wire contained in a tube sets up a rising stream in liquid contained in a closed system of which the tube is a part: a water-wheel, driven by the current, works the recorder.

400. *Schallenberger's* meter utilizes the principle of Tesla's alternating current motor: an iron disc, whose axis drives the recorder, is mounted within a flat closed coil of fine wire; this again is placed within another flat coil of thick wire carrying the current to be measured. This current does two things: (1) it magnetizes the iron disc; (2) it induces a current in the fine wire coils: the two coils being fixed at an angle of 45°, the induced current, which "lags" a quarter period behind the primary, pulls the magnetized disc round. The effect therefore depends largely upon those actions in wires and iron, which correspond to inertia and momentum in mechanics.

401. *Messrs. Wright & Ferranti* have utilized one of the many curious reactions of alternating currents and magnets which have been observed by Professor Elihu Thompson, many of which will no doubt be turned to practical purposes. A light metallic cylinder is carried by the axis of the recorder, and works in a space embraced by the curved polepieces of laminated iron attached to the laminated cores of a vertical electro-magnet. These pole-pieces, or horns, are "throttled," as it is called, by bands of copper surrounding them at intervals, in which currents are induced with the accompanying lines of force, as the successive magnetic impulses traverse the iron, when an alternating current is sent into the magnet. The lines of force set up eddy currents in the metal cylinder, and drive it round by the repellent action set up.

402. *The compounding principle* of shunt dynamos has been applied to many of the instruments described. One difficulty in meters is that there is the mechanical friction to be overcome, which is of greatest relative importance at the very time that the actual work to be measured is smallest; as a consequence, the meter will not start with a very small current, and produces an error of an irregular value. This is overcome by a closed circuit wire, doing no actual work, but using only a very small current, the resistance being so adjusted that it shall only just tend to start the motion under the ordinary E M F of the circuit. This small current, in fact, deals purely with the initial mechanical resistance to motion, and does it by producing a weak magnetic field independent of that produced by the working current which is to be measured.

403. PRINCIPLES OF MEASUREMENT.—Measurement really means ascertaining how many times a fixed unit is contained in the thing to be measured. Originally, no doubt, some familiar object was taken as the unit, such as the average barley-corn or some recognised "stone," and these arbitrary weights, &c., naturally grew up to larger ones by the process of doubling, generating the present system of weights and measures. The burden of the calculations these inflict upon commerce must ultimately induce even "practical" England to get rid of them, as the more generalizing French mind has long ago.

Exactly the same process has been followed in scientific matters; before the whole aspect of science had burst upon the mind of man, the more salient phenomena of each branch of knowledge were first observed; subsequent observations were referred to and compared with these, and thus grew up a set of merely "practical" systems of measurement based upon isolated facts, and even worse, expressed in the confusing system of common weights and measures. Hence, in electricity we have such measures of action as that referred to in § 382, and many similar ones, all based on isolated facts. As electricity assumed the state of an exact science, and was brought into subjection to mathematics, the evils of this system became so intolerable that an effort was made to remedy the nuisance, and an organised system of electrical measurement was devised by a committee of the British Association, which after some modifications by scientific congresses at Paris has found general acceptance as the international system of electric measurement.

404. Unfortunately this system, perfect as it is in itself, retains the original defect of being based upon a merely arbitrary and accidental unit, the metre, nominally a fraction of the circumference of the earth, instead of seeking a truly

scientific starting-point. This evil, which very few people even yet comprehend, is analogous to the errors of the old astronomy: it looked at the universe from the earth, and tried to bring all the observed motions into a system subordinate to the earth; hence inextricable confusion. As soon as man adopted nature's centre and looked at the universe from the sun, all confusion disappeared, and perfect harmony and simplicity were at once presented to the observer. Exactly so with every other science. When we want to weigh and measure nature, her forces and works, we ought to take for our units *measures which nature herself uses.* Of all the sciences, however, chemistry alone does this, and in consequence has made the most rapid progress, since this plan, otherwise known as the atomic theory, has been employed; for what is the atomic theory but the substitution for the incomprehensible and unmeaning relations of pounds weight or pint measures of matter, of the idea of *nature's unit, the atom of matter without reference to weight or size*, except when these are required for practical purposes, and then ascertaining the weight of each form of matter which nature has put into her unit of each element? More advanced chemistry has found that gaseous volume, rather than weight, furnishes the best starting-point for the atomic system. Now volume and weight are related to each other in the metric system, but again by the purely arbitrary (though practically convenient) intermediary of *water:* but water volume has no relation to the natural atomic system, while the volume of gaseous hydrogen has, and this relation would have furnished us, after some trouble in defining it, with a perfect system of universal measurement.

That brilliant chemist A. W. Hoffman saw the value of such a relation in chemistry, and proposed as unit the *crith*, one litre or cubic decimetre of hydrogen at 0° C. and 760 mm. pressure, weighing ·0896 of gramme. Either this or the cubic metre 89·6 grammes, would furnish a true natural starting-point for a general system; as pure gases double their volume with a fixed quantity of heat, this quantity would be the heat unit; as in doubling volume the weight of the atmosphere is lifted, that weight would be the work unit; as the same quantity of heat would raise the gas to a certain temperature, if it was prevented from expanding, it would give us a scale of temperature (if desired, one starting from absolute zero); and thus we should have the natural relation of heat and work in one unit, related also to the energy absorbed in chemical and molecular changes. But beautiful as this system would be, it is now unattainable, and we must make the best of the system at our disposal; it should however be understood that it is this fundamental defect of the accepted system which has compelled me to use my own or the "chemic" unit in this work wherever I have desired to make the natural relations of electricity intelligible. I have not retained that unit for any fanciful reason, or because it is my own, but simply because I could not exchange it for the ampère without wholly destroying the special feature of this book, viz. the treating electricity as a natural force connected to the equivalent, molecular, and atomic constitution of matter, instead of a purely artificial offspring of algebraic symbols. The same remark applies to my use of the "equivolt"; it is not likely that either will be really adopted by the scientific world; but they serve a purpose the accepted units do not fulfil, and furnish'constants for converting these units into electrolytic work, for which purpose probably it will yet be found necessary to add corresponding units, on the basis of the gramme, to the B A system.

It should, however, be clearly recognised that the accepted system is also a natural one in this sense, that it is based upon *energy*, while it ignores matter and its constitution; energy can be measured by any arbitrary units of mass, space, and time; the misfortune is that the unit of mass is not an atomic unit, and consequently the derived unit of electric quantity and current is not correlated to the chemical system of nature, except by a fractional figure, the coulomb and ampère electrolytic value.

405. THE B. A. SYSTEM.—This may be studied on two plans, the *theoretical* and the *practical*; the latter being derived from the first. It is of great importance to clearly understand both, and their relations, but they constitute two distinct systems, and many people can clearly understand and employ the practical system who find the theoretical one wholly beyond their comprehension. I shall therefore endeavour to so present the subject as to keep the two systems distinct, while exhibiting their relations. The mathematical expression of the phenomena of electricity, known as Ohm's law, is now universally accepted, and thoroughly satisfactory; it is entirely independent of any theory whatever as to the nature of electricity, but merely expresses the conditions of the observed facts; and to do this embodies them under certain heads. The fundamental idea is that *a force*, be it what it may, produces the observed effects; this force is concerned in all operations of mechanics, &c., and in electricity is represented by "attraction," § 89. Its necessary first consequence is a pressure or pull, tension, § 90, and a *tendency to action called* "potential," § 91, which in dynamic electricity *becomes* "*electromotive-force*," § 172, which is symbolized in

Ohm's formulæ by E. This is opposed by the various circumstances, molecular construction of the substances, insulation, &c., all of which are embodied in the general term "resistance," symbolized by R, § 171, which again simply expresses a fact, but no theory whatever. The result is action measured by the relation of these two, and called "quantity," Q; and when time is taken into consideration it becomes "current," or quantity in a given time, symbolized by C. This is often called "intensity of current," and symbolized by I: this mongrel term, derived from the translators of the French phrase "intensité de courant," strength or amount of current, leads to great confusion of ideas, because intensity has in the earlier English books a distinct meaning which corresponds to EMF, and has no connection with the current or quantity. The object of the B. A. system is to furnish a defined unit for each of these mathematical expressions, so that all the actions of electricity may be capable of exact definition and comparison with mechanical work.

406. Absolute Units.—A system of absolute units is one which does not consist of arbitrary, independent measures, but is based upon measures which are common to all kinds of operations; upon the fundamental elements, time, length, mass, &c., which enter into all physical operations. Any units might be used, such as the foot, pound, second, and for many purposes these are very convenient and have to be used: but for systematic purposes the necessity of the case limits us to some form of the "metric" system, which must inevitably supersede in time all other systems of measurement, even though these latter may be proved to have points of superiority.

407. Fundamental Units.—Before entering on the electric measures, it is necessary to understand the general system of which they are a branch. The fundamental elements, of which unit measures are required, are Length, Time, and Mass; of the first, two units are employed, the metre and the centimetre. The first has many advantages, but the second is being forced into use by the mathematicians, on the ground that the cubic centimetre of water furnishes the unit weight, the gramme. As it has been fully developed, and its units have received definite names, the centimetre system will be used here. None the less it is a serious inconvenience to practical scientific men that the metre has not been adopted as the unit of length. English men of science have gradually accustomed themselves to the metric measures and the various units based upon them, and students begin to understand what is meant by a gramme-metre as the unit *of work, and the calory* as the unit of heat, and now they

are being puzzled afresh by a new system. The fundamental units are:—

L, Length	1 Centimetre;
M, Mass	1 Gramme;
T, Time	1 Second;

from which it is called the centimetre-gramme-second, or C.G.S. system.

408. Derived Units.—From these are derived the general mechanical units: of motion, which is length traversed in unit time; velocity, which is motion in unit time; momentum, which is mass having unit velocity; force, which is a general expression for any cause which generates velocity, but for systematic purposes is defined as the cause of "momentum"; and work, which is the energy due to the action of the force.

Hence we have the following units:—

			Unit value.	Name.
V,	Velocity	$L \div T$	1 centimetre per second	—
F,	Force	$L \times M \div T^2$	ditto in 1 gramme	Dyne.
W,	Energy Work	$L^2 \times M \div T^2$	1 dyne in 1 centimetre	Erg.

We see here the connection and the distinction between Force and Energy. *Force* is measured by the *velocity* it sets up, the *momentum* generated, therefore by length, L; *energy* is measured by the *square of the velocity*, the vis viva, therefore by L^2. But while *unit* force and *unit* energy are the same value (one cause, the other effect, each equal to each), force and momentum increase in the ratio of *velocity* or L, while energy or vis viva increase in the ratio of the *square of velocity* or L^2, which means the arithmetical product, not the square, in the sense of "area."

409. Gravitation.—To understand these values it will be well to compare them with the familiar terms based on gravity; for gravitation is the only absolute natural force, and as it is constant in its operation, it generates not only a "velocity," but also "acceleration," that is to say, the moving body, retaining at each instant its acquired velocity, adds to this the growing velocity due to the force; but in dealing with the energy involved, the actual velocity at a given instant only is considered; regarded as a force in the abstract, gravity, *g* imparts a velocity of 32·2 feet, or 981 centimetres per second. Regarded *as* a unit force, it generates this velocity in a mass of one *gramme. This is* however, correct, only near London, for force

of gravitation (upon the earth) varies according to the distance from the centre of the "mass" of the earth; at the equator it is 978·10, at latitude 45° it is 980·61, at the poles 983·11, these being velocities in centimetres. Taking the value in England as 981, the force of gravity equals 981 dynes, or C.G.S. units of force. The actual force of gravity at any part of the earth is ascertained by the following formula: $g = 978 \cdot 1028 \times$ cosine $2\lambda - \cdot 000003\, h$, in which λ denotes the latitude and h the height in centimetres of the place above sea-level.

410. The *erg* may, therefore, be compared with the common mechanical unit of work, the foot-pound, because the ft.-lb. is the same thing as 138·25 gramme-metres, or expressed in C.G.S. system as 13825 centigramme-metres; then, if we take gravity g as equal to 981 dynes in this system, we find that the ordinary ft.-lb. is equal to 13,564,325 ergs. Such a figure shows at once that this system is really adapted only to minute measurements. To get rid of the numerous figures involved, a simple system of writing is adopted, and the above figures would be written as $1 \cdot 356 \times 10^7$ or 1356×10^4, and most of the calculations involved are thus reduced to the alteration of the index figures, resulting in loss of accuracy, because only round numbers are used, and fractions thrown out.

411. This system is becoming so common in electrical and scientific works, that it may be well to explain it. The index, as in logarithms, may be *positive*, signifying the "power"—that is, the number of tens by which the figure is to be multiplied, or *negative*, signifying the number of tens by which it is to be divided; thus the negative index written with a dash represents a *decimal fraction*, and we have—

$1 \times 10^6 = 1{,}000{,}000$, a million
$1 \times 10^3 = 1{,}000$ a thousand
$1 \times 10^2 = 100$ a hundred
$1 \times 10^{-2} = \cdot 01$ a hundredth
$1 \times 10^{-6} = \cdot 000{,}001$ a millionth.

In fact, the positive index, as in logarithms, is one less than the figures representing the number; but the negative index, unlike the logarithmic, is the number of figures representing the decimal when written out.

412. In naming these values, we are burdened with a barbarous nomenclature; thus, a million ergs is called a megerg or an erg-six, and so on, adding the index number to the name of the unit. Further, in electricity, we have the prefixes mega, signifying a million, as the mega-volt or meg-ohm; and micro signifying a

millionth, as the micro-farad, besides the ordinary prefixes of the metric system of measures.

413. ELECTRICAL UNITS —In all measurements we need a separate starting-point or "unit" for each order of things, though these units may be derivable from the few fundamental units—thus, from the unit *length*, 1 centimetre (or metre or feet, as may be), we derive unit *area*, the square centimetre, &c., and from this again, unit *volume*, the cubic centimetre, &c. In like manner, each separate conception or order of facts in electricity requires a unit of its own, and the system is similar to that of the mechanical units. Here, also, we start from a "force" generating a velocity. We can now replace the attraction of gravitation by two distinct attractions of electricity. We have the force exerted by an electric "charge," § 89, from which is derived an electrostatic system of units; and we have the attractions exerted by an electric "current" upon a magnetic pole, or upon another current; this furnishes the electro-magnetic system of units. The static system has been examined, § 87, and does not call for much attention. The unit of the magnetic system is based on the unit magnetic pole, which is one which repels a similar pole, one centimetre distant, with a force of one dyne, § 150. The unit electric current is that which, in an arc of one centimetre length of a circle of one centimetre radius, will repel a unit pole at its centre with a force of one dyne. The unit current would also, in a length of one centimetre, repel a similar current at a distance of one centimetre with a force of one dyne; that is to say, such a length forming an arc of a circle of 1 centimetre radius would produce a unit field of force, § 149, at its centre, and more generally a current C in a circular arc produces a field equal to C × length of arc ÷ square of radius, from which are derived the formulæ § 354.

The easiest method of forming a concrete idea of these forces is to conceive a spring balance adjusted to carry a weight of $\frac{1}{981}$ of a gramme. Any force which strains the spring to that point is exerting unit force. Thus, if a magnet-pole, one centimetre from another magnet-pole, required the spring to be stretched to that point to resist motion (that is, to maintain the centimetre distance) a force of one dyne would be exerted; or, if the balance were graduated to successive increments of that value, it would indicate the number of "dynes" exerted by any force. The ultimate idea of force is *pressure* or *tension*, attraction or repulsion, really in unit degrees, but for purposes of calculation expressed in relation to mass.

414. The two systems of units are related to each other in a ratio expressed in the formulæ as v. The actual value is not

exactly known; but it is interesting for two reasons. It has been experimentally determined by several eminent electricians by different processes.

Weber and Kolrausch ..	310·74 × 10^8 c,m, per second
Sir W. Thomson	282·5 " "
" another mode	293· " "
Clerk Maxwell	288·
Ayrton & Perry	298·
Professor Rowland	299·5
Professor J. J. Thompson	299·58
Average	295·9 × 10^8 c,m.

Sir W. Thomson's latest determination is stated to be within half per cent of 300,000 kilometres per second. These variations, though not large, show (like the different values found for the ohm) that while mathematicians work out their formulæ to the extremest nicety, the data are by no means settled.

The other point of interest is that this ratio, which is really a velocity, is apparently identical with the velocity of light—the various determinations of which range over much the same values as the above. Much stress is laid on this by the advocates of Clerk-Maxwell's suggestion of the identity of nature of light, electricity, and magnetism.

415 Dimensions.—The values of the various units of the system are derived from considerations classed under the name of "dimensions"; derivations in fact from the unit length L, mass M, and time T; which dimensions, therefore, are alike applicable to any actual values given to those units in any system.

Electric Units.

Units.	Electrostatic System.	Electro-magnetic System.	E. Static. / E. Magnetic.
EMF	$L^{\frac{1}{2}} M^{\frac{1}{2}} T^{-1}$	$L^{\frac{3}{2}} M^{\frac{1}{2}} T^{-2}$	$L^{-1} T = \frac{1}{v}$
Resistance	$L^{-1} T$	$L T^{-1}$	$L^{-2} T = \frac{1}{v^2}$
Current	$L^{\frac{3}{2}} M^{\frac{1}{2}} T^{-2}$	$L^{\frac{1}{2}} M^{\frac{1}{2}} T^{-1}$	$L T^{-1} = v$
Quantity	$L^{\frac{3}{2}} M^{\frac{1}{2}} T^{-1}$	$M^{\frac{1}{2}} L^{\frac{1}{2}}$	$L T^{-1} = v$
Capacity	L	$L^{-1} T^2$	$L^{-1} T^2 = v^2$

MAGNETIC UNITS.

Strength of magnetic pole m $= L^{\frac{3}{2}} \quad M^{\frac{1}{2}} T^{-1}$
Moment of a magnet $m\ l$ $= L^{\frac{5}{2}} \quad M^{\frac{1}{2}} T^{-1}$
Intensity of a magnetic field H $= L^{-\frac{1}{2}} \quad M^{\frac{1}{2}} T^{-1}$

416. The units thus ascertained represent each its own idea, thing, or action, as shown by the dimensions which represent their values, but the system is so related that we may actually treat them as though they were all one absolute unit, representing all forms of force and energy, cause, agency, and effect; we may multiply and divide them by each other as though they were abstract numbers merely, instead of concrete things. In the first edition, this feature of the system was so much dwelt upon, that some readers overlooked the fact of the inherent differences among the units, which has induced me to point it out more particularly now. The arithmetical unity of relation is, in fact, the great advantage of the use of an absolute unit, and it results from the fundamental principle of the system—viz. that a unit force, acting in unit time and unit mass, will produce a unit effect or operation, and expend or produce unit energy in some of its manifestations. Therefore the ratios or actual values of the units themselves are fixed by this necessity. Starting from any two, the rest follow of course.

This relation, in fact, involves that unit quantity Q must pass through the unit conductor (miscalled resistance), R, in unit time, under the influence of unit E M F or E, constituting unit current C; and in doing so must expend unit energy upon unit work, and be capable of being stored in a receiver of unit capacity, and of exerting unit force upon a unit pole or current. Hence, all being alike represented by 1, and being all interrelated, there follows the fact mentioned, that we can treat them as simple numbers, without regard to their actual natures.

417. PRACTICAL ELECTRIC UNITS.—The units employed by electricians and forming the B. A. system, were selected so that they should be of a convenient magnitude, and yet be decimal multiples of the absolute units of the metre or centimetre-gramme-second absolute system, and also approximate in value to units already in use. But the means of measurement being at first imperfect, the actual values of the units of resistance and current were not correctly ascertained. Then a congress at Paris endeavoured to fix new values before accurate knowledge was obtained, and with that curious tendency of the French mind towards apparent definiteness, they fixed upon a value for *the ohm, even* then known to be incorrect, merely because it *avoided a fraction* in the nominal length of a tube of mercury

which no one ever made, or probably ever will make in reality. The result is that at this moment no human being knows what a "volt" is, though electricians talk about it solemnly enough, and we hear of true volts, legal volts, the B A volt and Rayleigh's volt: while theorists will work them out to several places of decimals, it is the simple fact that the values of the units are so uncertain that they may involve an error of quite 2 per cent in the calculations. It is a great pity the practical units are not defined upon the C.G.S system simply, and any errors of the standard merely covered by calculation until sufficiently accurate knowledge is attained.

418. The VOLT is the unit of *electromotive force*, and symbolized by E; when of the nature of an opposed or *counter electromotive force*, as in the case of a reversed cell, a voltameter, secondary battery, &c., it is written $-e$. The volt is, therefore, the unit of all the expressions or actions, which are either consequences or parts of electromotive force, or which are simply other names for the same thing, such as "potential," "difference of potential," "electric pressure," and "electric force," and it is now becoming common to speak of them simply as "the voltage."

The volt represents a static force or pressure; there exists no standard of it at present, but it is purely a matter of calculation. It is of the value of 10^8 C.G.S. units (10^5 M.G.S.). This value was selected as being the nearest approximation to the Daniell cell, which is the most constant known; the volt is Daniell ·9268. Its value is really defined as that E M F which sends an ampere current through an ohm resistance, and the confusion mentioned, § 417, is the consequence of varying values given to these.

As the E M F developed in a thermo electric battery is constant for a fixed range of temperature, and as the freezing and boiling points are easily producible, it is probable that a standard volt might be constructed by this means; but it would not be reproducible exactly, because any variation in the purity of metals alters the conditions; it could, however, be copied like the ohm.

419. The OHM is the unit of what the electricians call *Resistance*, for the true explanation of which term see the Chapter on Resistance. It is symbolized by R when general, but when it is subdivided into the several parts of the circuit it is written r, r^1, &c. Its value is 10^9 C.G.S. units, and this value was chosen as a near approximation to the Siemens mercury unit, which was largely in use, and is a column of mercury 1 metre long and 1 millimetre section, at the freezing point of water. To give a definite idea of the ohm, it may be said to be equal to a wire of

copper of 95 per cent. conductivity, such as is ordinarily obtainable, 10 feet long, ·01 inch diam. (or 10 mils. about 32 gauge), weighing 2 grains per foot. Any other wire, of whatever material or size, or any electric circuit which would equally divide an electric current with this wire, would be 1 ohm of resistance.

The exact value of the standard ohm prepared by the B.A. committee is not known certainly. The following list of the different experimental determinations shows both the difficulty of these exact experiments, and the real uncertainty which still exists as to the data upon which mathematicians build up elaborate calculations.

1862.	Weber	1·088
1870.	F. Kolrausch	1·0196
1873.	Lorenz	·9797
1876.	Rowland	·9912
1877.	H. F. Weber	1·0020
1883.	Lord Rayleigh	·9867
1887.	Rowland	·9864

As these differences are found by most skilful experimenters, aided by the most perfect and complete appliances, it is not a matter of surprise that the actual units obtainable vary considerably from each other, especially as the determination of the true conductivity of pure mercury forms part of the problem.

420. It is now customary to express these values in terms of the length of a column of mercury of 1 square millimetre section. At the Paris Congress it was resolved that a length of 103 centimetres should be adopted as the *legal ohm*. That length was known to be incorrect, but it was an even figure. However the English Post Office refused to adopt it, the Americans paid no attention, and though we read occasionally of *legal* ohms, and *legal* volts as a consequence, the thing has no existence or use.

The B.A. unit is still employed in the Post Office and by most people, for the simple reason that it would be a very costly process to change the instruments, and let what will be decreed by any future Congress, in all probability the B.A. unit will continue in use and be corrected in calculations by means of a constant.

It appears probable that a length of 106·3 c.m. will be adopted before long as the new *legal* ohm, as that appears to be the value of 10^9 C.G.S. units according to the most trustworthy experiments.

421. There have been many discussions as to the best way of constructing a standard and reproducible ohm. Mercury is

superior to any solid metal, because it is capable of easy purification, and is subject to no molecular changes; but how the column of mercury is to be produced is questionable, because there is no mode of securing a tube of exact section, and the adjustment of fractional lengths is difficult. The plan which I have suggested gets over this; let a V-groove be formed in ebonite or glass, exactly 1 metre long, or two such grooves side by side, half a metre long, and connected by massive copper at one end, so as to have the terminals side by side; this being placed exactly level, let so much mercury be put into the grooves as shall exactly make the ohm: this would make its own section, and all that would be necessary would be to ascertain exactly the weight of mercury required; weight and length, the two easiest measures to determine exactly, are all the data which would be required; a cover applied would complete the apparatus, with suitable arrangements for keeping it at the proper temperature.

422. The AMPERE is the unit of *Current*, or quantity per second, the one thing which has an actual value in nature, which value is not, however, taken into account in the system. The unit value of current is defined of necessity by the relations of Ohm's formula—

$$\frac{\mathrm{E}}{\mathrm{R}} = \mathrm{C}. \quad \frac{\mathrm{EMF}}{\mathrm{Resistance}} = \mathrm{Current}. \quad \frac{\mathrm{Volt}}{\mathrm{Ohm}} = \mathrm{Ampère}.$$

$$\frac{10^8}{10^9} = 10^{-1}\ \mathrm{C.G.S.} \quad \text{or} \quad \frac{10^5}{10^7} = 10^{-2}\ \mathrm{M.G.S.}$$

The ampere was formerly called the veber. Its actual value is not yet ascertained satisfactorily, and the difference of values given is considerable. The value accepted until recently makes the ampere a current which, doing work in electrolysis, releases ·00001022 gramme of hydrogen per second, or in grains ·000158, and the equivalent proportion of any other substance. M. Mascart found the value, gramme ·000010415 of hydrogen, which is in grains ·000161.

Lord Rayleigh's latest determination, which is likely to become the accepted value, is a deposit of silver per second, gramme ·001118 which corresponds to hydrogen ·0000103518.

Nitrate of silver 15 or 20 parts in 100 water is used and is probably the most trustworthy substance for actual measurements, because the equivalent of silver being 108· reduces the effect of small errors; the nitrate of silver is also easily obtained pure, and there is little risk of producing basic salts, provided the density of current is kept low. But for ordinary purposes the sulphate of copper is satisfactory.

This value, and the change in value of the ohm will affect the correctness of many of the figures which will be given in the Chapter on Electromotive Force.

The *ampere hour* is a larger unit coming into use for electric light purposes, and is used as a unit of quantity, being the value of 3600 coulombs, or ampere seconds.

423. The COULOMB is the unit of *Dynamic Quantity:* it is of the value of 1 ampere of current during one second; that is, a current of 10 amperes would transmit in one second 10 coulombs of electric quantity; the coulomb is, therefore, C.G.S. 10^{-1}, and represents chemically, ·000158 grain of hydrogen, or such values as have just been described for the ampere-second.

424. The FARAD is the unit of *Capacity*, and its value is coulomb÷volt, or C.G.S. 10^{-9} units (M.G.S. 10^{-7}). That is to say, that the capacity of a condenser is the number of units of quantity it will receive under unit force. The value given is that of the electro magnetic system, and a unit condenser would therefore be one holding 1 coulomb under 1 volt potential. It will be seen, § 107, that the unit of capacity on the electrostatic system is a sphere of 1 centimetre radius, which would hold the quantity defined, § 87, so that on this system the capacity of the earth is calculated as 630 millions e-s units. *But all this belongs to the electricity which has been invented by the schoolmen;* as to the earth, there is no evidence that it has any static charge as a whole—i. e. as a sphere in space: it has many local charges, constantly varying, set up between parts of its surface and the surrounding atmosphere and clouds. Its capacity is imaginary, but the figure is useful to give some conception of the meaning; dividing this charge by the ratio v^2, § 414, we have $63 \times 10^7 \div (3 \times 10^{10})^2 = 7^{-13}$ C.G.S. units, and the micro farad being 10^{15} this is 700 micro-farads or about 2400 miles of cable, and gives ·1104 millionth of a grain of hydrogen as the chemical equivalent of the electricity which would charge the earth to the potential of 1 volt.

425. The MICRO-FARAD is the practical unit of capacity, as the farad itself is out of all practical use. This is the one-millionth of a farad and may be represented by 3·5 miles of average telegraph cable: see § 107 p. 67, and the table p. 71, where the natural truth as to capacity is fully explained.

426. The JOULE or JOULAD is the unit of *Energy expended.* It is the work done per second by the ampere in 1 ohm, and its *expression is* $J = C^2 \times R$. This is the energy expended, the *work done in passing* the current through the circuit. *It is the*

true resistance, and is analogous to mechanical friction, and like it, varies as the *square of the current*. As the formula E × C means exactly the same thing for any given circuit (only substituting a measured current for a measured resistance), this formula also gives us the result in what are called volt-amperes, which are the same thing as the joule.

The *joule* covers all forms of energy, and includes W work in foot-pounds or other measures, and H heat in calories, &c. Therefore it needs a constant *k* to be added to the formula, which gives the value in the desired terms. Thus the joule means :—

C.G.S. (ergs)	·10^7
M.G.S., 1000	·10^3
Foot-pounds	·7373
Calory	·24065*

427. The WATT is the unit of *Power* (similar to horse-power); it holds much the same relation to the joule as the ampere does to the coulomb. It is, in fact, the power to do a joule of work, and is of the same value per second as the joule, or equivalent to 44·25 foot-pounds per minute, or horse-power (33,000 foot-pounds per minute)·00134: so that

1 horse-power = 746 watts;

that is to say, one horse-power expended wholly in producing electric current would generate

1 ampere current in 746 ohms resistance,
or, $\sqrt{746} = 27{\cdot}3$ amperes in 1 ohm ,,

In fact, we may consider the joule as the cost of carriage per ohm of one ampere, but with the charge increasing as the square of the number of amperes carried per ohm.

428. The *volt-ampere hour* is a larger unit of energy corresponding to the similar current unit, § 422, used in connection with electric lighting, and represents 3600 joules.

The *Board of Trade unit* for electric lighting, to which some have given the atrocious name of "Bot," represents the energy expended by 1000 amperes under the pressure of one volt, during one hour; that is, it represents 1000 volt ampere hours.

429. *Alternating intermittent currents* obey Ohm's law as to the relations of E. M. F, R, and C, at each instant of their existence,

---

* Two values in calories are given, ·24065 here, and ·2381 in the table. The first is that hitherto used, and ascertained by experimental observations: the latter is the theoretical value derived from the C.G.S. system; the difference is caused by the imperfect determinations of the standard units, the ohm and ampere.

these relations giving the ordinates of the curve of each particular current; but they cannot be expressed by the ordinary formulæ, because the varying conditions of each circuit, and the rate of interruption—the "*frequency*," introduce the disturbing element called "self-induction" and other names now replaced by the general term "inductance." This really acts in two ways, as E M F, and as an additional resistance, both vanishing, as the "capacity," electric and magnetic, of the circuit is satisfied. The formulæ therefore becomes

$$\frac{E_{,} - > e}{R + > r}$$

For practical purposes it may be represented as a temporary resistance for which a measure has become necessary now that alternating currents are brought into great practical use.

430. The HENRY is pretty sure to be the name of the unit of inductance, although a congress at Paris (1889) has decided to call it a "quadrant" and its introducers, Professors Ayrton and Perry named it the "secohm." These latter names explain the meaning of the unit in the system of dimensions. An ohm is said to be a "velocity" and a velocity multiplied by a time is a *length*. So inductance is said to be a length, L, and its unit is an "ohm second" which is the length of an earth "quadrant" or 1,000,000,000 centimetres.

The unit is so recently proposed that it is scarcely possible yet to give a popular conception of it, and the apparatus for measuring it is too complicated for use except in well equipped works and laboratories.

A paper read by Mr. Kenelly to the Institute of American Engineers, and to be found in the 'Electrician' Vol. xxvi. pp. 267, 305, gives the fullest information at present available.

431. *An alternatiug current of* 1 *ampere* means that "the square root of the time averages of its strength in amperes is unity," according to the proposed definitions. As a matter of fact there is no such thing, as the current varies from instant to instant, but it is practically necessary to express the average of these as "the current," and it is found that the true average is not the mean of the currents at each instant, but the square root of the mean of the squares of those currents—that is to say, it is related to the energy expended. This can be measured on galvanometers adapted to the purpose, and it is known as the "effective current."

432. *The voltage of an alternating current*, the "effective E M F" *is subject to the same* remarks, it is measurable by the Cardew *voltmeter because this* registers the actual energy used in heating

its wires, and the direction of the current in that wire does not affect the result.

The formula E.C. does not give the energy of an alternating current, nor is the resistance calculable as with steady currents.

433. Further information as to the principles which underlie these units will be found in the chapters relating to the several branches, and the following table will present the relations of the units to each other and their values in one view.

PRACTICAL ELECTRO-MAGNETIC UNITS.

Subject.	Symbol.	Name.	How derived.	Values of Units.		
				C.G.S.	M.G.S.	Practical.
E. M. F. . .	E	Volt	Ampere × Ohm	10^8	10^5	Daniell ·9628
Resistance .	R	Ohm	Volt ÷ Ampere	10^9	10^7	Siemens' 1·026
Current . .	C	Ampere	Volt ÷ Ohm	10^{-1}	10^{-2}	Hydrogen equivat. Gramme ·00001022 Mascari gives „ ·000010415
Quantity . .	Q	Coulomb	1 Ampere	10^{-1}	10^{-2}	
Capacity . .	K	Farad	Coulomb ÷ Volt	10^{-9}	10^{-7}	
„ practical	..	Micro-farad	„ 1 millionth	10^{-15}	10^{-13}	3·5 miles of average cable.
Energy . .	J	Joulad	$C^2 \times R$	10^7	10^3	10^7 ergs.
„ as Work	W	„	$E^2 \div R$	„	„	ft. lb. ·7373
„ as Heat	H	„	$E \times C$	„	„	Calory ·2381
Power . . .	..	Watt	1 Joulad per sec.	10^7	10^3	Horse-power ·00134
„ . . .	..	Volt Ampere	W ÷ time	„	„	44·24 ft.lbs. per min.
Electrolytic Current	..	*Chemic*	Ampere = 5·68	..	..	1 grain Hydrogen in 10 hours.
Energy	..	*Equivolt*	6338 Joulads.	..	..	4673 ft. lbs.

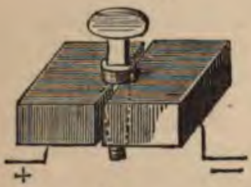
434. RESISTANCES MEASURES.—These are definite resistances made up into sets for use, precisely as weights are in ordinary weighing, and these known measures are compared with the one to be measured until the two are equal, in relation to electricity, as the weights are as to gravitation, by a process so similar to that of weighing that the apparatus is called a "Balance." The earliest were simply lengths of a particular wire; then Wheatstone's Rheostats were devised, these being wires of which variable lengths were capable of being measured off: one form consisted of a length of fine wire wound upon two parallel cylinders geared together, the one of wood with a screw thread cut in it, the other metal, so as to make contact with the wire wound upon it, leaving the length on the wooden cylinder to form part of the circuit: the other was also a wooden cylinder with a stouter wire wound upon it, forming a screw thread against which pressed a travelling wheel on a

metal arbor. In both instruments there were appliances for indicating the number of turns and parts of a turn which were left in the circuit: but both were very imperfect because the contacts were unreliable. Then fixed coils of wire were used and mounted in sets, and from these have grown up the instruments now used containing assorted sets of coils adjusted to ohms, or any convenient multiples.

The instruments described here will be chiefly such as students and amateurs can construct for themselves; for large operations many varied forms are devised, but once understanding the principles, any intelligent person can vary the construction to suit his purposes.

435. Resistance Coils.—These are easily made up to any resistance. They are commonly mounted in sets, giving 1000, 10,000, or 100,000 units, and are very expensive instruments, owing to the great labour of adjustment. The usual plan is to make up coils corresponding to the required divisions and connect the several terminals to massive blocks of brass arranged nearly in contact, so that a hole bored at the middle of the opposed edges will connect the adjoining blocks when filled up by a slightly conical metal plug. Fig. 44 shows the mode of connection which is largely employed in electrical instruments and gives an excellent connection, *if kept clean.* When the plugs are inserted, the circuit passes through them and there is no resistance; by removing a plug the current has to pass through the wire whose ends are connected to the two blocks. These blocks are commonly screwed upon a plate of ebonite or wood, &c., which allows dust, &c., to collect; they should either be sunk into ebonite, which could be done before this is hardened, or else all the spaces should be filled up with pieces, so as to leave a smooth surface with no openings but the plug-holes.

Fig. 44



436. To reduce the number of these connections, it is usual to make up the coils on the same principle that chemical weights are divided, viz. 1, 2, 3, 6, as by combination of these, 10, or any of its subdivisions, may be obtained; in other cases the combinations of 1, 2, 3, 4 or of 1, 2, 2, 5 are used. These combinations have the advantage of requiring only four reels and four adjustments to each decimal series; they are therefore *cheaper to make* in a large way; but they are more troublesome *to use than instruments* with complete decimal sets as described

below, as they require more arrangement of the resistances, and they are more conducive to mistakes, as they necessitate the adding together the resistances opened. In these instruments there is a complete wire circuit all through, and the plugs "short circuit," or shut off so much of the wire as may not be required. In the next form, on the contrary, there is no through wire, but such lengths as are required are thrown into circuit by a single connection for each decimal set.

437. DECIMAL RESISTANCE INSTRUMENT.—Consideration of the various advantages and evils of these instruments, both in principle and convenience of construction by amateurs, led me to devise an arrangement, which—writing as I do expressly to aid those who wish to construct instruments for themselves—I will now describe. In giving its mode of construction I shall endeavour to furnish such practical observations as my own experience indicates may obviate difficulties likely to arise in the construction. The instrument described gives resistances varying from 1000 ohms to 1–1000, but for convenience of making and facility of reading, the elements are arranged in regular sets of nine exactly similar parts, the terminal connections arranged as in Fig. 45, which represents one decimal set for any division. Each segment represents a connection § 438. C, the centre connection, leads either to *o* of the next series or, in the last, to the terminal screw. A glance will now show that the current enters at + which is connected to *o*; if this is connected to C, the circuit passes from this to the next series, while if C is connected to any of the numbered studs, just so many divisions of resistance are included in the circuit.

FIG. 45.

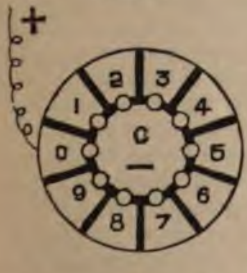


FIG. 46.

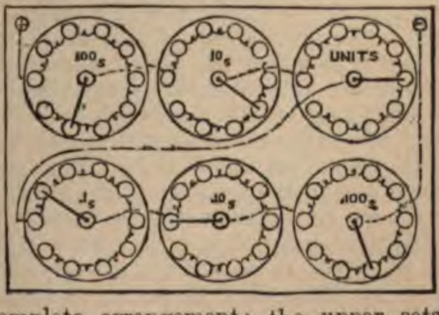


Fig. 46 shows the complete arrangement: the upper sets represent whole numbers of units; the lower sets, the decimal divisions; all arranged in the usual mode of placing figures.

The resistance as it is shown, therefore, reads off 865·107 units. The dotted lines represent the fixed connections, and the path of the current may thus be readily traced through the diagram.

438. CONSTRUCTION OF RESISTANCE INSTRUMENT.—(1) *Connections.* These may be like Fig. 44, but composed of a circular block and a ring of segmental blocks with holes to connect any segment to the centre, as shown, Fig. 45.

They may be a central pillar with a spring traversing over a ring of studs or segmental blocks; the spring should be wide enough to pass from stud to stud without break of circuit. This plan is very quick and handy in use, but is only suited to large resistances; the varying pressure of the spring, the coating of the studs with dust or smoke, makes a great difference in the contact resistances. If employed, the spring should press strongly, and all the faces be well gilt. The best plan, but troublesome in some respects, is to use mercury cups, connected together by a bridge of stout copper wire. The cups are easily made by using for the top a thick piece of wood (say 1½ inch), boring holes through, and filling the lower half of the holes with a copper rod or screw, the end of which, as also of the links, should be first well amalgamated. Brass screws will not do, as mercury penetrates them, and iron is objectionable, as being likely to disturb neighbouring galvanometers. The ends of the screws which project through the wood should be first tinned, ready for soldering the wires to them. See also § 362.

(2) *The coils.* The wire is usually laid upon reels; these may be of brass with a screwed end to go into the blocks: one end of the wire is soldered to the reel. If mercury cups are used, and the instrument cannot be turned over, it is better to arrange short coils horizontally, instead of longer vertical ones; fix to the middle line of the lower side of the top, a vertical board from which the proper number of rods project, and slip the reels on these. From each of the copper screws of the cups bring two stout wires out to the side of the top, along the edge, for connecting the ends of the coil wires to when mounting. The adjustment can then be made conveniently as the instrument stands, the coils being all accessible and removable. The wire, cut in lengths a little in excess of the resistance required, is doubled and laid so upon the reel; this avoids any induction in the wires, as the current is everywhere reversed, and it also prevents the coils from acting as magnets upon neighbouring galvanometers.

Another mode is to divide the length of the reel in two parts by a partition and wind half the wire in one direction in one compartment, and then reverse the winding in the other compartment: this is less perfect than the two contiguous wires, but the wire is more easily laid, and leakage is less probable. The two ends are to be left out for connection, and in fine wires it is desirable to join a stouter wire (or a short piece of copper wire) on them to reduce risk of breaking just outside the coils. If preferred, the middle of the wire may be within the coils, so that the two ends are outward and accessible.

It is not necessary to lay the wire on reels; it may be doubled and rolled up in small coils if preferred; this exposes more surface, and the heat can escape more freely, but is more trouble in fitting up.

(3) *The wires.* These should be German silver, or the new alloy, platinoid; it is usually silk-covered, but cotton is nearly as good. It is desirable to saturate the covering with paraffin, by baking thoroughly dry and dipping while hot into melted paraffin. This can be done either before or after laying on reels. German silver wire varies very much in resistance, according to the amount of nickel in it. Of two wires of exactly the same gauge, No. 26, 8 feet of the best balanced 11 feet 6 inches of the commoner; therefore, the suitable sizes cannot be given, but must be ascertained by aid of the tables of wires.

It is useless to measure lengths of wire, because the resistance varies in each length, owing to slight variations in thickness, and still more to slight changes of quality, and the finer the wire the greater this variation. Thus, in No. 18 two trials differed only a quarter inch; in No. 34 many trials gave results varying from 6·4 to 7·2 inches. It is useless also to adjust wires before winding, as the strain upon them alters their size slightly, and so affects the resistance, and this the more if, as should be done, soft wires are used.

The size of wire is to be selected according to the purpose of the instrument. If it is to be used as an actual resistance for varying currents (and such an instrument is essential) large wires must be used, to avoid the effects of heating by the current; if it is required only for measuring resistances with the bridge, as only small and momentary currents pass, finer wires may be employed. The following sizes are suitable:

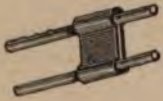
Single ohms ..	No. 18.—21	100 ohms ..	No. 25.—34
10 ohms	„ 20.—29	1000 „	„ 32.—40

Decimal sets need not be all of one-sized wire: the larger sizes may be used for the first coils, and finer as the resistance rises.

(4) ***Adjustment.*** This is effected on the principles described

§ 455, by balancing against a standard. The ends of wire left for adjustment are well cleaned, and shortened by crossing in contact till closely correct, when they should be twisted together and soldered, and this continued until it exactly equals the standard. The following is a more perfect plan. Having by mere contact, as before, ascertained closely the proper length, slide upon the two ends (first tinning them with the soldering iron) a short piece of brass tube, also tinned, which is best done by boiling in a tin vessel with a solution of caustic soda, adding a little oxide of tin (putty powder) and some granulated tin and press it together so as to grip the wires firmly. Slide the wire ends through this, watching the galvanometer till the resistance shows closely right, or a trifle too small; then touch the joint with a soldering iron, and allow it to cool completely. The final adjustment is to be made by filing away the joint so as to lengthen the wires, or the wires themselves, so as to increase the resistance until correct. With fine wires it is well to join on stouter ends for this adjustment; there is also a great advantage in soldering on a second wire near the adjusting point, so that the circuit there is double: the effect is that any change of resistance involves a double change of length of wire, and also there is less risk of complete break of circuit; this may be carried further by making this second loop of much greater length than that of the wire it affects. When adjusted, the coils suspended from the top can be inserted into a case, which is to be secured by a few screws to the top, and forms the stand of the instrument. For further details of construction see § 455.

FIG. 47.



(5) *Subdivisions of an ohm.*—These may, for ordinary purposes, be made by division of a length. Take 1 ohm in No. 16 German silver wire; measure into 10 parts, and at each division solder a copper wire, to be taken as close up as possible to its connection. A copper or brass wire, No. 18, may be balanced against one of these tenths, and so furnish hundredths in like manner, and a length of No. 10 will give thousandths. The subdivisions may be balanced singly by a standard ohm, using the multiplying ratios of the bridge.

(6) *The fixed resistance.*—The permanent connections should be made with very stout copper, the whole of the connections arranged for short circuit (that is from o to C), and this fixed resistance measured, and added in calculations to the resistance *shown.* For use with the bridge it is well to use a pair of conductors in the proper opening, and to balance against these and

the fixed resistance a length of wire which, being cut in two, is to be used to connect any resistance to the measure; then all but the actual resistance shown is neutralized, unless multiplying ratios are employed.

439. MEASURING RESISTANCES.—Electric resistances are measured by comparing them with other resistances of known amount, and the processes are of two kinds: (1) The comparing of *currents* produced against the resistances. (2) The comparing the *electric pressures or difference of potential* between two conductors. The first system may be applied: (1) By Ohm's laws, calculating the resistance from the known E M F and current. (2) By observing, with a galvanometer, the currents produced under given conditions; then replacing the resistances to be measured by a set of measured resistances, and altering these until the same deflection is obtained. (3) By a differential galvanometer, as described § 365. This process depends upon the laws of derived circuits, and directly balances the currents themselves against each other.

440. THE WHEATSTONE BRIDGE.—The second principle, that of comparing *potentials* purely, without any reference to the *currents* passing, is that of the Wheatstone bridge, so called because a cross circuit is produced between two points of equal potential. It is also, and more appropriately called "the balance," because that connection does as truly balance the circuits against each other as the weighing balance does the earth's attraction upon bodies on its opposite arms. It is also called "the parallelogram," because it forms a parallelogram of forces.

The principle and the use of the instrument is extremely simple; but the books make it a very mysterious subject buried under algebraic formulæ, which make people imagine that it is hopeless to try to understand it. The principle is that of a Rule-of-Three sum applied to the law of derived circuits, that the current will divide among all the branches in the inverse ratio of the several resistances.

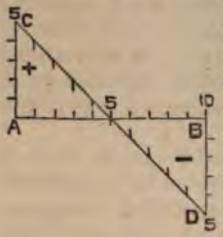
441. The distribution of potential is equally simple, if we clearly distinguish between E M F and potential, with their relation to current. E M F is the initial or exciting cause existing at the zinc plate in the liquid of a galvanic cell, and *nowhere else*. To think of E M F as existing in the wires, only causes confusion. But E M F sets up a molecular strain throughout the whole circuit, which constitutes the "difference of potential" between any two parts of the circuit, and is distributed (as what may be conveniently called *electric* pressure) over the circuit in exact proportion to the resistances. This conception *treats potential* as single, and reckons it as "above

earth or zero," §§ 91 and 104. But as it is an artificial representation of the facts, it will be well to show how it properly represents the conditions of the electric circuit.

442. Wherever we open our circuit, we find a positive and negative condition, a + and − pole of equal and opposite forces, these being simply the opposite faces of the particles in the circuit, §§ 42 and 124.

We should therefore begin by thinking of "electric pressure" as twofold, as representing the opposite stresses of these particles. Fig. 48 presents this view, and shows how the force is distributed. A B is the circuit (which is regarded as a resistance divided into 10 equal parts), starting from the face of the liquid A C, in contact with the zinc, and returning through the negative plate and the outer circuit to the zinc plate, B D. Treating the E M F as a unit, and calling its value 10, we have + and − pressures, each 5, or a *difference of potential* of 10, equal at the point of origin to the E M F, and drawn to the same scale as the resistance. The line C D is, therefore, the line of distribution of potential, which is likewise divided into 10 equal parts, vertical lines from which show the pressure existing in any part of the circuit. Thus from any points on the line of potential C D, lines to the line of resistance A B will cut off a resistance equal in proportion to the sum of + and − pressures, included in the intermediate conductor, and acting to set up current in it.

FIG. 48.



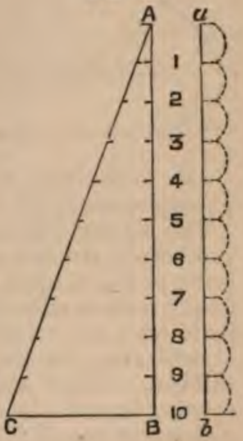
It should be remembered that the actual values of the E M F and potential, or resistance, are of no consequence. Let them all be great or all small, or one small and the other great, these *ratios or proportions* will hold good.

443. As yet we have regarded Fig. 48 as representing a whole circuit and force, but it applies equally to any fraction of a circuit. Remembering the distinction made between E M F and potential, yet if we take any portion of a circuit, and ascertain the difference of potential between the extremities of that portion, we may regard that as the E M F acting in that portion. Let A B be only a tenth part of the circuit, then if the same total E M F is acting, the actual difference of potential, constituting the force within this section of the circuit, will be only 1 (equal to one-tenth of the acting E M F) instead of 10, but its *proportionate distribution over the included resistance will remain unaltered.*

444. But further, these same conditions apply equally if A B, this portion of a circuit, instead of being a single path, be two or many; the total current will divide itself among the paths in the inverse ratio of their resistances, no matter how these differ, and the potential will be distributed in each of these *derived circuits* over that resistance in proportionate ratio. To show this, it is more convenient to treat the difference of potential as single, instead of a compound of + and −, especially as this gives us conditions which enable us to compare electric potential or *pressure* with the pressure of water.

Fig. 49 represents a two-branch circuit with the several pressures, but these are not, as before, on the same scale as the resistance, but merely proportional. Let us first regard the lines A B, *a b*, as vertical pipes, connected to the same reservoir of water at an elevation which produces a final pressure B C, *b c* equal in both. Now dividing the lines of height and those of pressure, each into 10 parts, or, what is the same thing, dividing A B, *a b* equally, we get lines which represent the pressure existing at each level of the pipes; but, let us now suppose that one of these pipes, instead of being vertical, goes from A to C, or that it goes to any distance away which shall lengthen its path to the level, or let it follow the dotted line between the sections, still in each proportion of length corresponding to the level of the vertical pipe A B, there will be exactly the same pressures in A B, A C, and *a b*. Therefore, at any such level or line of equal pressure we might place a cross-connecting pipe between A B and the other pipe, and there would be no tendency for water to pass through it. But let a connection be made between, say, 2 in A B, and 5 in *a b*, and water would pass along this connection, from A towards *b*.

FIG. 49.



445. The analogy holds when we consider A B, *a b*, to be two electric circuits, branching from one conductor at A *a*, and B *b*, the potential is the same at every equal proportional part of the resistance, and at such points connections may be made, and there will be no tendency for electricity to pass across the connection, because, *although there will be such a tendency at each point, it will be met by* an equal but opposite tendency at

the other end of the cross-connection. A galvanometer in this cross-connection will show no current passing; an electrometer would show no signs of charge. This will hold true, though the one resistance be a thousand times as great as the other; still, at the definite proportional points, equal pressures or potentials exist, and no current can pass across. Fig. 50 shows the lines of Fig. 49 arranged thus, as derived circuits, forming part of a main circuit from a battery. If a connection were made between any of the opposed points no current would pass, and it would divide the circuit A B into the four arms of the bridge. Fig. 51.

FIG. 50.

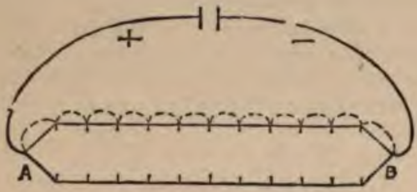
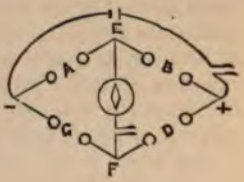


FIG. 51.



446. CONSTRUCTION OF BRIDGE.—Fig. 51 explains how these principles are applied in the ordinary bridge.

The battery wires are led to the two screws from which the two branch circuits + B E A − and + D F C − start, + and − being points of equal pressure for both circuits. E and F are fixed points in either circuit, connected to a galvanometer which indicates a current passing as long as E and F are not equalized. It will show no action when the conditions of balance are fulfilled. There are thus four branches produced, and an opening is made in each for the purpose of introducing such resistances as will fulfil the conditions of balance; those conditions being that the four branches shall hold among themselves the relations of the elements of a Rule-of-Three sum: as long as they do this the relations may be varied to suit each case. Let us call the resistance in each branch by the letter placed in its opening. Then either

1. As A is to B so is C to D.
2. As A „ C „ B „ D.

It is convenient to treat one of the openings or branches as the unknown resistance to be measured, and C will be so used. *Then the law* is that this resistance (C) is to the one on either *side of it as the* one on its other side is to the fourth. As a consequence, when there is balance the battery and galvanometer may be exchanged in position without disturbing balance.

447. Fig. 52 shows that we have thus four arrangements at disposal:

1. Equal branches and equal circuits.
2. Unequal branches and equal circuits.
3. Equal branches and unequal circuits.
4. Unequal branches and unequal circuits.

Fig. 52 shows that 1 is analogous to the ordinary weighing balance, and 2 to the ordinary steelyard. It shows also by inspection which condition is the best, for throughout all nature it will be found that relations which can be expressed symmetrically are superior to those which are irregular. No. 1 is the best, and it will always be found that measurements made with all four branches alike are most accurate. Number 2 is next. These are liable only to actual errors of instruments or observations, but in 3 or 4 those errors are multiplied by whatever ratio is employed.

FIG. 52.

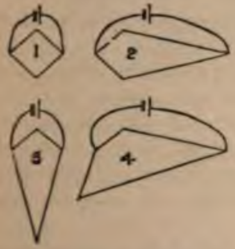
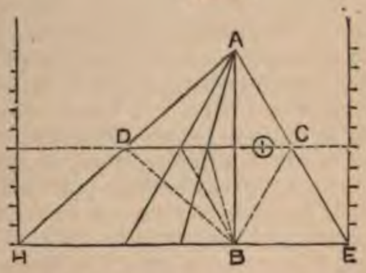


FIG. 53.



448. The whole of the principles are exhibited in Fig. 53 The line H E is the theoretical *zero of potential*, while the vertical lines are *scales of potential* corresponding to A B, Figs. 49, 50, and also mark the actual difference of potential included in the bridge, which is completed by the points D C, as shown by the dotted lines, to complete the four arms of the bridge, Fig. 51. As long, therefore, as the position of these points keeps the line D C horizontal, that is, parallel to the zero line H E, these points are equally related to the scale of potential, and no current would flow along the line D C, in which the galvanometer is inserted. But if the proper ratios are not maintained between the arms, *then one of* the points D C would obviously *be lower than the other*, and current would flow to it. D C,

therefore, exactly resembles a balance arm in the ordinary scales for weighing,

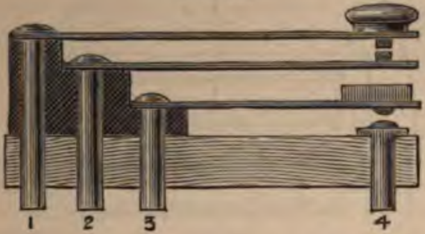
449. *The galvanometer* should be one of a resistance approximating that to be measured, but very sensitive, the needle closely astatic, and suspended by a long fibre. Of course this element is not susceptible of much alteration, but for small resistances a good astatic galvanometer suits; for large resistances the Thomson's reflector is best. The law for arrangement of the galvanometer resistance is that it should equal the joint resistances on either side of it; but the best use of this law is to show with a given galvanometer what is the most sensitive arrangement of the three fixed branches. There should be, as shown, Fig. 51, a commutator in the galvanometer connection, in order to prevent the needle from being thrown about by alterations in the branches; it also enables us to make contacts in time with the rate of swing of the needle, and thus either to keep on increasing this swing, to get a noticeable deflection, or, by opposing the vibrations, to bring the needle quickly to rest. This commutator allows any inductive actions (which act as temporary resistances § 429) to occur while the galvanometer is out of circuit. There should also be a commutator in the battery circuit, to allow current to pass only when needed, to avoid heating the wires. For a similar reason, as well as for economy, as small battery power as possible should be used. For all small resistances, one or two cells of a good battery will suffice, but larger resistances, of course, require more, in order to set up a sufficient difference of potential in the wires, to allow a small range of resistance to send a current through the galvanometer. As only momentary currents are needed, a good manganese cell or two will answer, but a bichromate cell is generally useful.

450. Fig. 51 is necessary to make the principle of construction clear, but the actual instrument need not take that form. So long as the two circuits are properly provided, their connections may be arranged in any way. Thus a board 6 in. × 3 in. and a dozen binding screws will make a bridge; a piece of stout sheet copper, 2 in. square, cut across diagonally and holes drilled near each corner to pass binding screws through, will make the two ends; and two strips 3 in. long, each containing three binding screws, will make the middle portion of the two circuits. It is still more convenient not to set the binding screws for + and −, E and F, in their places, but to take connecting wires from those points and lead them to a pair of screws at one end for the battery, and a pair at the other end for the galvanometer. A more perfect arrangement is to lead

one of each of these pairs of wires to a commutator fixed on the stand, and from there to the binding screws.

451. *The best commutator* for this purpose is one which makes the two contacts successively with one touch, as shown in Fig. 54.

FIG. 54.



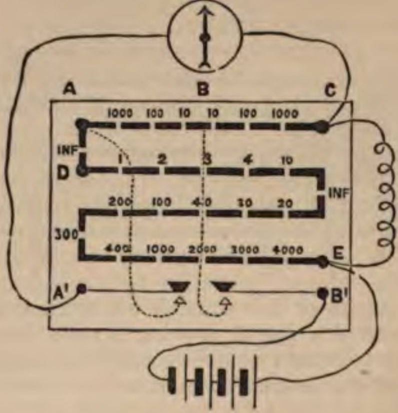
A block of ebonite or dry wood is cut with three steps, and upon each is secured a spring, having a stem passing through the block for a conductor: on the faces of the upper two springs are soldered platinum contact pieces, and also on the lower face of 3, and the top of the stud forming the fourth connection; insulating pieces of ebonite are cemented to the faces of 2 and 3; 1 and 2 form part of the circuit from one of the battery binding screws to the + or − point of the bridge, while 3 and 4 are part of the circuit from E to F to one of the galvanometer screws.

452. We have thus an excellent skeleton of the bridge, which requires the means of filling up the openings A B D to complete it: one of these is, of course, a resistance coil, § 437. For the other two openings we require two equal or proportional resistances, which may be mere lengths of wire, but should be two properly fitted resistances, variable as required. The best is a set made like the resistance instrument itself, with 1, 10, 100, ohms, and so on, which, being made all continuous, require coils, 1, 9, 90, and so on, with the power of throwing the required length into circuit. The best plan is to combine all these resistances and the bridge in one instrument.

453. COMBINED BRIDGE AND RESISTANCES.—Fig. 55 shows the ordinary post-office pattern arranged to act as a bridge. The right-hand commutator is that of the current, from which it will be seen the circuit goes to the middle of the upper line which is the two variable resistances (as in B D, Fig. 56). The resistances from D to E are the branch A, Fig. 57, and between C and E the branch C, the resistance to be measured. The uses of the instrument are the same as that to be next described.

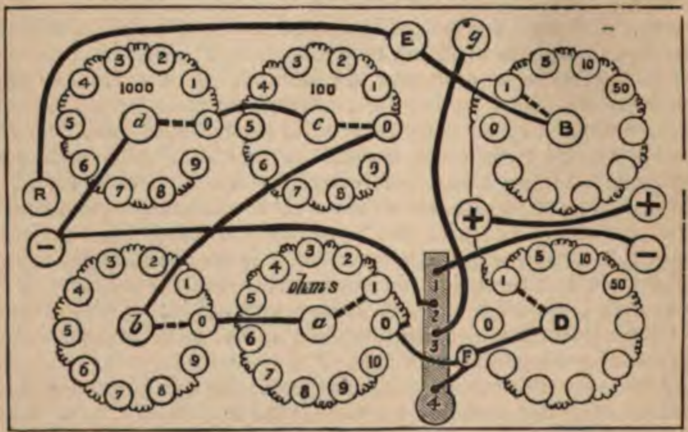
When both Inf. plugs are in place the instrument can be used as a direct resistance throughout, between C and E.

Fig. 55.



454. Decimal Combined Bridges.—Fig. 56 shows such an instrument, devised upon the principles of § 437. The lettering

Fig. 56.



of the parts corresponds to that of Fig. 51, so that it is easy to *trace the connections* and the manner in which they fulfil the conditions of the bridge; + and − are the binding screws for the battery wires, and their connection may be traced to + within the instrument, and through the commutator to − at the other end, these being the points at which the real bridge (the derived circuits) commences. B and D are the two variable resistances of each circuit, one of which, D, is continued through *a*, *b*, *c*, *d*, the resistance measure, ranging from 1 ohm to 10,000; the other branch goes direct to E, and is then continued to R, which forms with − the connections for the resistance to be measured, and thus constitutes the fourth branch. The neutral points E F are connected to the galvanometer screws, one direct, the other through the commutator to *g*, which with E is the connection for the galvanometer. The instrument is shown as arranged for ordinary measurements, as though measuring a resistance of 1 ohm. By means of the multiplying ratios it would measure a million ohms or the thousandth of an ohm. It may also be employed as a direct resistance through R and −.

It might be better to divide the circles into 11 parts, so as to make each set complete without throwing any others into series. This is done with the single-ohm set, as otherwise there would always be some difficulty in making up even numbers, and there would be 1 ohm short of 10,000. For convenience in use it would be better to place the bridge coils B D at the other end so as to use the left hand at the commutator, while the right made the requisite changes of resistance. It would be an advantage also to make openings in the wires R E and − 2 in which coils could be inserted, adjusted to balance the connections when using multiplying ratios.

455. The *mode of construction* is identical in principle with that described § 437; but the explanation is given here how to build up the complete instrument from a single standard ohm, where the maker has not another instrument to copy. A temporary bridge, such as is described, § 450, is required, and at least four exactly similar wires, as conductors for use in the openings A C. Two similar wires should be soldered to F and + within the instrument, unless mercury cups or binding screws are inserted there, as these are the starting points of the various resistances. To avoid confusion in the lettering, during the rest of this description the letters which relate to the temporary bridge will be enclosed in brackets.

Connect the battery and galvanometer to the bridge, and place the standard ohm in (A) with two long wires of near an ohm resistance, and as nearly as possible alike in (B) and (D); and in (C) a wire, which make to balance the ohm. Now change *the wires (B) and* (D) one for the other; if they were exactly alike (A) and (C) should still balance; if they do not, shorten one of the wires (B D) till balance is again produced, and ascertain the exact difference of length necessary for the purpose; shorten the wire by *half* this length and readjust (C); now, if care has been taken, balance will be undisturbed when (B D) are again exchanged. In all cases this must be ensured before any reliance can be placed upon measures taken. Make in (C) two exactly similar ohm coils, which should be terminated, not with binding screws, but with No. 10 copper wire, to go into the screws of (B D), and ascertain, as before, by exchanging, that they are exactly equal, as on this will depend the accuracy of the instrument. They may be incorrect ohms if it so happens, but they *must be exactly alike.*

These being in (B D), connect the standard in (A) by two of the equal conducting wires, and by two others connect (C) to F and + in the instrument, and adjust the coil of D 1 to one ohm exact, inserting the shifting connection as shown. Then insert the connecting wires from (C) in 0 and 1 of *a*, and adjust the first ohm coil, the two ends of which are soldered to those connections. If mercury cups are used, this is done by amalgamating the ends of the conductors, and dipping them into the cups, or two of the conducting wires can have plugs on one end, if plugs are used. In this case it will be desirable to have holes bored *in* the segmental blocks (corresponding to Fig. 45) forming the ring of connections, by which to make direct connection to each separate coil. Screws may afterwards be passed through these holes to secure the blocks to the top of the instrument. If other connections are used, a copper wire should be attached to each, long enough to be conveniently attached to and form part of the conductors. Repeat this with each of the ten separate ohms, adjusting them one by one.

Now disconnect the standard ohm and insert the two wires from (A) in *a* 0 – 5 and those from (C) in + and F as before, and adjust D 5. Then including *a* 0 to 10 in (A) make in (C) two approximate 10-ohm coils. Place these in (B D) of the bridge, with the same precautions as before of exchanging and equalizing them, and make a correct 10-ohm coil for use in (A) of the bridge. Using this as the standard ohm was used, go through exactly the same stages as before, and so adjust D 10, *b* 1 to 10, and D 50. When this is done, *a* and *b* together will furnish the basis for a 100-ohm coil, allowing in the connecting wires for the extra resistance of the fixed connection between *a* and *b*. Go through the same process with *c* and *d* till the whole *10,000 ohms are* built up and those of D completed to such extent *as is desired.* The coils of B may be also adjusted at the same time, and in a similar manner with those of D, by using the E connection instead of F; but it will be much better to balance them direct by the instrument itself against those of D by connecting in turn in R – the standard, 10, 100, and 1000 ohm, coils, and opening equal resistances in *a*, *b*, *c*, *d*. The fixed connections shown in thick lines are secured to the lower face of the top, and as they form the closed circuit of no (measured) resistance from F to –, they should be of the stoutest copper convenient, such as No. 10 doubled, as this resistance is a source of inaccuracy with multiplying ratios. See end of § 415. The connection between R and E is to be also of copper, and to exactly balance the other connection, by putting F – (the movable connections being all on *o* of each set) in (A) of the bridge and E R in (C), and adjusting the length of this to balance. This should be done before adjusting the coils. If all is correct, with 1 ohm in R and – and one in B, *a b c d* ought to balance the ohm, or such multiples as D is set at should be required; which last is unlikely to be exactly realized by any not well practised in adjusting. In each of the sets, care should be taken that any little residual errors should be alternately opposite, so as to rectify each other as the resistance increases, instead of the error accumulating. While adjusting, the greatest care must be taken not to hold the wires in the hand, or to expose them to any unequal heat; and when that is necessary, as in soldering, to allow them to cool perfectly, otherwise the resistance will be wrong.

456. In using this, or, indeed, any form of bridge, it is desirable to make it a rule to always connect the battery and galvanometer in one way, so that the deflection tells at once whether the resistance is too great or too small. When exact balances cannot be attained, as when part of an ohm is required, observe the opposite deflections produced with too small or too great resistance; the difference will show how much to allow.

457. *The British Association Bridge* was especially devised for adjusting standard ohms. It is provided with a length of platinum iridium wire, with a scale and a moving clamp which corresponds to the point + in the previous figures, and by slightly moving it, and consequently the length of wire in the branches A C effects the purpose described for correcting erroneous wires. There is also a reversible commutator for changing the relations of C D, and true balance is attained when this reversal produces no effect on the galvanometer. There are a variety of forms devised for different purposes, but the principle is alike in all.

458. *Condensers* may be used instead of resistances in the

branches, and an electrometer in place of the galvanometer, for measuring capacities.

A *telephone* may be used instead of a galvanometer, provided either that intermittent currents are passing in the branches, or a break to produce intermittence is inserted in the galvanometer circuit.

459. *Variable Resistances* are useful in operations where either a definite current is needed, or very gradual changes have to be made. For such purposes the old rheostats, § 434, are still useful, but they have the defect of causing irregular jumps; two wires can be stretched parallel to each other, with a sliding contact-piece connecting them, but this also gives irregular contacts: either of the following plans gives a very steady action.

(*a*) A strip of wood has two V V grooves cut along it, as in the suggested ohm, § 421, which contain mercury, the one pair of ends fitted with connections, and a sliding bridge of copper wire joining the two grooves at any desired point.

(*b*) Two glass tubes are mounted vertically upon a stand, their lower ends containing copper rods attached to connecting screws: two straight copper wires hang in the tubes, their upper ends being solidly connected together, and fitted with a cord passing over a pulley upon a frame double the height of the tubes; the tubes being filled with mercury, the raising of the wires alters the resistance gradually.

The wires should be well varnished all over except at the ends, which should be amalgamated; carbon rods can be used instead of metal wires, and a series of such pairs of tubes fitted upon a stand will give any convenient range by proper selection of size and material.

If desired, scales can be placed behind the wires, and the value of the elevations marked upon them.

This plan may even be extended to considerable resistances, by using tubes containing sulphate of copper and allowing electrolysis to occur from the wire ends; but in this case the current should be frequently reversed. A similar variable resistance can be made with a long trough of copper solution with a plate fixed at one end, and another movable along the length.

460. *Very high resistances* can be obtained by the method of Mr. S. E. Phillips: a piece of very finely ground glass has a continuous line drawn upon it as a spiral or ziz-zag, with a good black lead pencil; the terminals can be clamped to it, preferably by holes drilled in the glass, and the surface varnished.

I have made high resistances of a lower range by securing tin foil, first on thick paper and then on ebonite, and cutting, out a spiral or ziz-zag line, so as to leave only a continuous line of the foil of such a width as suits the purpose, and varnishing the whole when quite dry with shellac.

Probably a useful resistance might be made by drawing such lines upon glass or ebonite with gold size, and then applying gold leaf or Dutch metal, in the usual way of gilding.

461. *Black lead* and other forms of carbon have the advantage that they change resistance by temperature in the opposite way to metals; it is therefore possible to produce resistances nearly unchangeable by temperature, by combining a carbon resistance with one of metal, in such proportion as to nearly balance each other in this respect.

462. Even the common black lead pencil will produce very convenient resistances; the ends should be cut as if for use as pencils, then soaked with varnish and covered with gold leaf over which a wire is secured in good contact, and the point of the pencil rubbed away to expose the black lead in close contact with the gold leaf; a coating of copper being deposited makes a secure end and good connection, and a length of German silver wire can be wound on the pencils for the purpose of balancing variation; of course these are not easy of adjustment as the quality and resistance vary a good deal; but they may be useful for many purposes. I have made several giving from 20 to 40 ohms resistance.

CHAPTER VI.

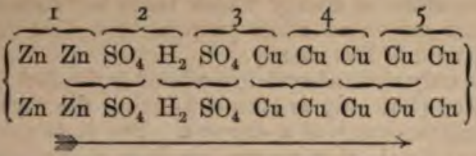
CURRENT.

463. A sketch of the general principles of current electricity is given §§ 168–173 and in §§ 418–422, to be fully worked out under the different heads of Force, Conduction, and Current. It is better to reverse this order in examining these details, because Current deals with actual tangible facts in nature, while the others are matters of calculation. Current, in electricity, as with water, means the rate of passage of unit quantity across any section of the conductor: its most definite evidence and measure is the chemical action produced (§ 169), which will be dealt with in the Chapter on Electrolysis.

464. The term "current" is derived from the old fluid notions, and originally conveyed the idea that there was an actual transmission of the fluid along a conductor, corresponding to the flow of liquid in a pipe. This idea has been superseded, but is not yet definitely replaced, because we do not really know what is the mode of action. It appears that the most probable is a rotation of the molecules of matter without change of place that the quantity or rate of current means the number of such molecular rotations occurring at a cross section of the circuit, and that this again may be related to either, (1) the number of molecular lines, §§ 15 and 391, along which action occurs; or (2) the rate of rotation occurring in each such line: each rotation implying a unit of (possible) chemical action within the conductive circuit, and a unit magnetic action around the circuit as well as a static electric stress in the inductive field; the two latter absorbing energy at the commencement of a current, which it returns when the current ceases, but in no way influencing the current while it remains steady.

465. That some such action occurs where current traverses an electrolyte is pretty certain, because, as the two halves of the electrolyte appear separately at the electrodes, it is evident some action must occur in the body of the liquid which enables them *to be separated.*

Such an action may be represented thus—


1 2 3 4 5
Zn Zn SO4 H2 SO4 Cu Cu Cu Cu Cu
Zn Zn SO4 H2 SO4 Cu Cu Cu Cu Cu

In the upper row, brackets 1–5 show the molecules of the substances, 1 being the zinc surface, 4 the copper electrode of a Daniell cell, and 5 the conducting wire: the lower brackets show the new molecules formed by one chemical reaction which impels energy (as explained in Chapter on E M F) into the polar line § 391, producing a rotation along the whole of that line, which is "current," and transmitting energy as a line of shafting or a row of wheels would. This is the electrolytic action: the lower line is to indicate that the same idea may be applied to metallic conductors if we conceive the terminal atoms of two lines to unite together to form fresh molecules, instead of becoming free as in electrolysis. This conception covers all the facts of current, and explains an apparent transmission of matter with a real transmission of energy; an apparent velocity without longitudinal motion of matter; and the generation of heat in the ratio of the "square of current" or of the rate of rotation.

466. A new doctrine is becoming fashionable of late years, devised chiefly in order to bring the now important phenomena of alternating currents under the mathematical system. It is purely imaginary (see § 330), based upon Clerk-Maxwell's electromagnetic theory of light, itself correctly described by a favourable reviewer as "a daring stroke of scientific speculation," alleged to be proved by the very little understood experiments of Hertz, and supported by a host of assumptions and assertions for which no kind of evidence is offered; but its advocates now call it the "orthodox" theory.

This theory separates the two factors of electricity §§ 19–21, and declares that the "current," the material action, is carried by the "so called-conductor" (which according to Dr. Lodge conducts nothing, not even an impulse, and according to Mr. O. Heaviside is to be regarded rather as an obstructor), but the energy leaves the "source" (battery or dynamo) "radiant in exactly the same sense as light is radiant," according to Professor Silvanus P. Thompson, and is carried in space by the ether: that it then "swirls" round (cause for such swirling no one explains) and finds its way to the conductor in which it then produces the current which is apparently merely an agency for clearing the ether of energy which tends to "choke" it, while the conductor serves no other purpose than that of a "waste pipe" to get rid of this energy.

467. The only tittle of evidence offered is the fact that energy is transmitted (but only as stresses) during the variable period of the commencement of a current. But it is a known fact, and admitted by all, that no one has been able to discover any single trace of any action in space during the continuation of steady current. Even the known cases of such transfer are only momentary, while conditions of stress are being produced: in no single case is there any evidence of its passing from the "source" to work, it is always found to proceed from the conductor, often many miles from the source, and the agency is always the lines of stress of magnetic force or of static induction, the former of which depends upon the number of turns made by the conductor (the ampere-turns), and the latter can be traced only between separate parts of the conductor as difference of potential. On the other hand, during steady current we have every evidence that the energy of the source is wholly contained in the conductor, and issues from it either as heat proportioned to the resistance, or as work done by mechanism, which is also measurable as resistance.

468. This much, however, is certain; that if the "ether" or medium, or di-electrics carry the energy, the practical electrician must not imagine he can get nature to do his work for him; the ether, &c., play no part whatever in the calculations he has to make; whether copper wire is a conductor or a waste pipe, that is what he has to provide in quantity and quality to do the work; if gutta percha, &c., really carry the energy, he need not trouble about providing *for that purpose;* he must see to it that he provides it according to the belief that it prevents loss of current. In other words, let theoretical mathematicians devise what new theories they please, the practical electrician must work upon the old theory that the conductor does his work and the insulation prevents its being wasted. Ohm's law (based on the old theory) is still his safe guide.

For this reason I would urge all practical electricians, and all students who desire to gain a clear conception of the actual operations of electricity, to dismiss from their minds the new unproved hypotheses about the ether and the abstract theory of conduction, and to completely master the old, the practical, and common sense theory which links matter and energy together, and which agrees with all the related knowledge we possess of chemistry and mechanics. Until some real evidence is offered, no matter what eminent men accept these new notions, they are no more than *make-believe knowledge*—drafts upon the treasury of science, with no assets to meet them.

469. Let us now consider the essential facts of which we must take account in order to understand what goes on in the circuit. We have—

(*a*) Current, equal at every cross section of the circuit (when once fully established), including the source: this is not transformed into work, or diminished, once set up, by any of its actions. This is admittedly a phenomenon of the conductive circuit (see p. 66).

(*b*) *Magnetism* existing in closed rings in and around the conductor; equal in every part of circuit in like conditions; proportionate to the current, and to the number of turns of the conductor; controlled also by the *magnetance* or permeance of the matter influenced.

(*c*) *Chemical functions* proportioned exactly to the current, and related to the molecular structure of the electrolytes which form part of the conductive circuit.

(*d*) *Chemical energy* related solely to the chemical affinities of the substances the current travels by and acts upon: that is to say, to the nature and structure of matter.

(*e*) *Heat* developed in the conductor, proportioned to the "resistance" (or non-conductance) of the several material substances which form the circuit; that is, to the nature of matter: proportioned also to the square of the current, in perfect analogy with all cases of velocity in mechanical friction, according to the practical theory. According to the "abstract" hypothesis, it is a pure waste of energy to relieve the medium, and produce the current as a mode of dissipating energy uselessly.

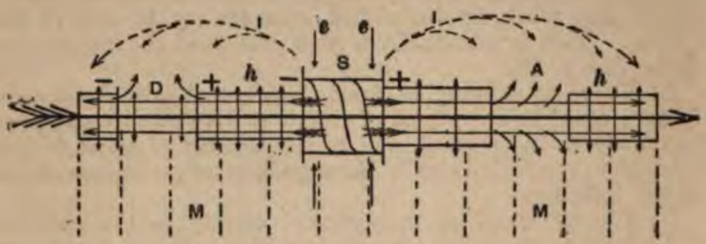
(*f*) *Static electric stress* or charge outside the conductor proportioned to the "voltage" or E M F at each part of the conductor, and specially related to the nature of the surrounding di-electric, that is, to the properties and structure of matter

(*g*) *Electric pressure*, or stress, within and around the conductor, between any two of its parts: proportional to the E M F or difference of potential; to the intervening resistance of the conductor; and measured by the slope or fall of potential; this is independent of the nature of the surrounding di-electric, but is the measure of the energy expended in each portion of the circuit.

470. It will be noted that the structure and nature of different forms of *matter* play a prominent part in most of these functions; but the properties of "ether" have nothing to do with any of them, except *on the pure* assumption (for no one ever tested or

ever can test ether itself) that this wonderful substance is a di-electric, and possesses unit capacity: this may be, or may not be; it is a mere matter of guess, or of assumption, for the convenience of mathematical operations, to which actual truth matters nothing if the assumption enables a theory to be worked out.

FIG. 57.



471. Fig. 57 is intended to exhibit the properties of the circuit, on the "practical" theory. S represents the "source" as a turbine, for sake of the hydraulic analogy; the arrows *e e* show energy supplied from without in the case of a steam-driven dynamo, but from within in the case of a battery; the central arrow is the usual symbol of current, while the four internal arrows represent energy issuing from the source in both directions in the circuit, as fact requires (see § 121).

472. The student meets with many difficulties, and the practical man is subjected to many misapprehensions, because the terms used have altogether altered in meaning of late years, and do not convey the same sense as the same words have in their ordinary use. In the older works on Electricity "quantity" and "intensity" currents were spoken of, and even now we occasionally meet with the unmeaning words — the "tension" of a current; all terms giving the impression of some difference of nature in currents are misleading. Current, as such, has only one quality, its rate: a given current, that is one which will produce a certain deflection in a particular galvanometer, or will deposit a certain weight of metal from a solution, is exactly the same in its nature and properties, whether it comes from a large or small cell, from a single cell or from a thousand cells in series. But the same current may have different effects according to its *density*, that is according to its ratio to the sectional area of the conductor, or its quantity *per* unit of area: this influences the temperature generated in wires, and is of supreme importance in electrolysis. The term

intensity of current is explained § 405, but some writers, anxious apparently to add to the confusion of terms, have used this already misapplied term in the same sense as "density of current" is used here.

473. CONDUCTION. — Ohm's laws or formulæ are universally employed by electricians, but are not confined to electricity, for if examined they will be found to express the common fundamental mechanical laws. The relations established by Ohm's laws between electromotive force, resistance, and the current and its work, are simply the well known laws of mechanics or the relations between force, such as gravity, weight, and velocity; and the formulæ are merely mathematical expressions. Invaluable in dealing with the modes of operation, they only delude us if we regard them as facts, and do not clearly trace out the reasons why they are valuable. The importance of these considerations will be evident if we clearly see that, in consequence of misunderstanding this, and by converting mathematical formulæ, which are nothing but mental tools (apparatus for mechanical thinking in some sense), into actual facts and theories, electricians have actually been led into great errors as to the nature of the electric constants.

Speaking of the possibility of utilizing natural forces, such as waterfalls at a distance, that eminent practical and theoretical electrician, the late Sir W. Siemens, once said—"My critics have, however, fallen into the error of overlooking the fact that half a unit resistance is the same for a circuit capable of working one lamp as it is for working 100 or 1000 lamps. *Electricity is not conducted upon the conditions appertaining to a pipe conveying a ponderable fluid*, the resistance of which increases with the square of the velocity of flow. It is, on the contrary, a matter of indifference what amount of energy is transmitted through an electric conductor; the only limit is imposed by the fact that, in transmitting electric energy, the conductor itself retains a certain amount proportional to the transmitted, which makes its appearance therein in the form of heat." We have here two distinct statements—1st, that in electricity a resistance is the same to all currents transmitted; 2nd, the sentence italicised, that currents of electricity and currents of water depend on different laws. Sir W. Armstrong also said "in the case of a fluid current through a pipe, the resistance to the flow increases as the square of the velocity, while in the case of an electric current through a given conductor it is a constant proportion of the energy transmitted. So far therefore as *resistance* is concerned, electricity has a great *advantage over water for* the transmission of power." Advanced electricians do not now fall into this error, but students are almost universally deluded and puzzled by the fact that the term "resistance" has in electricity a meaning wholly different from that which it bears in mechanics and in ordinary language. Even yet eminent electricians will assert that the conduction of electricity and water is different in principle and law; but the direct result of the principles now to be investigated will be to prove that *water in pipes and electricity in wires are conducted upon identical conditions,* though by altogether different processes.

474. OHM'S LAWS.—The fundamental expression is $\frac{E}{R} = C$, force (more correctly "potential") divided by resistance defines the current.

It follows that any two of the elements, E, R, and C, being known, we can calculate the third, using the proper units.

Current. $E \div R = C$. Force and resistance being known.

Electromotive Force. $C \times R = E$. Current and resistance being known.

Resistance. $E \div C = R$. Thus, with any cells the E of which is known in volts, dividing by the current in amperes, gives the total resistance in ohms; and deducting the external R we get the internal resistance of the battery.

Energy = C^2, the square of current, in unit, or unaltered conductor, or $C^2 \times R$ as a general law (see § 426).

It will be seen that C and R are each the reciprocal of each other multiplied by E; that is to say that R and C limit each other under any given conditions of E.

475. The usual expression of the meaning of the formula is, *Current* is *as the Force* and *inversely as the Resistance.* In order to fix the mind upon the ideas I wish to develop, I give this modified definition, *Current* is *as the EMF* (which is *potential,* § 91) and *as the conducting capacity.* That which in the usual expression *is called resistance,* is simply the *reciprocal of the conducting capacity* of the circuit, now commonly called the "conductance."

476. According to these relations, C varies as E, but energy, as work or heat, *which are the true resistance,* varies as E^2, that is as the square of either C the current, or E the EMF in unit or any unaltered conductor, and also as the so-called resistance, that is, it is inversely as the "conductance." This is the ordinary law of mechanics, say in friction, where work absorbed is as the square of velocity, and as some other element, such as weight.

477. The first point as to which a clear understanding is necessary, is whether these symbols E, R, and C have any realities *behind them.* Do they represent facts, and if so, what facts? *Or are they merely* mathematical expressions, simple tools of

thought? If the latter, we must carefully avoid the error of mistaking them for facts, lest, like the monster Frankenstein, they prove too much for their creators. It will be more convenient to examine this while studying Ohm's formula as a whole, than to treat each head singly in its separate chapter.

478. *Electromotive Force.*—Is the E M F which we symbolize by E, *a force?* Let us see what idea we can form of it. An agency tending to set electricity in motion, or to set up that motion which we call electricity. Here it will be seen we have two considerations; an effect, the motion produced; a cause, the force producing the motion. Of these the first is of necessity an actual fact, though we may hold different ideas as to what is the thing. But does the *cause* exist, as a special force? There are actual forces having real existence, such as the various attractions of which we may take gravitation as the type: these are, so to speak, self-existent—we know not their causes. But there are other agencies which we call forces, yet which have no actual existence. They are transformations of energy, and are forces only in the mathematical sense.

479. *Development of E M F.*—When we dissolve zinc in a battery this force makes its appearance, § 164. It is said by some to be due to the contact of the two dissimilar metals. But one thing is certain, this force can do no work unless it is maintained by an equivalent supply of energy, and, as a matter of fact easily proved, the degree of electromotive force produced is measurable in terms of the energy transformed, set free in the chemical combination.

But if we expose the junctions of two different metals to heat, we find electromotive force set up in degrees depending (1) upon some inherent property of the metals, and (2) upon the difference of temperature produced, which means in fact the quantity of energy which can be thrown into the circuit.

Similar results are found when we examine the E M F set up by dynamo machines. It bears a definite relation to the energy expended. We find also that though electromotive force is constantly acting upon the circuit, it has no accelerating action. We therefore conclude that it has no actual existence, but is due to conversion of energy, and that it must in some way be equivalent to the energy which it expresses.

The effect of the ideas about to be presented is that E M F (or potential) is an expression for a measure of the effort of energy to become kinetic under special conditions of the molecular structure of the matter with which it is associated; this effort is manifested as "electric pressure" measured in volts.

480. *Any agency may be called a force* which is capable of

setting up motion, or altering the conditions of motion in a mass of matter. Thus, if we take a ball of lead and let it fall, motion is imparted to it by gravitation. We may push the same ball of lead along a table, or by muscular energy hurl it to a distance; we may strike it, as a cricket ball is put in motion, by a percussive blow; or we may, by aid of a gun, set it in motion by means of compressed air or by the explosion of gunpowder. In all these cases motion is produced, and we may call the agency in each case a "force."

481. *Mechanico-motive Force.*—We may embody all these in one expression, and say they are due to a "mechanico-motive force," the intensity of which can be measured by its capacity to produce momentum. Of course the object of this term is to obtain an exact mechanical counterpart to the electric expression, but this term, or something like it, has actually been employed in mechanics. We have then to see whether this mechanical analogue is a force, or what is its true meaning.

482. *Static and Dynamic Force.*—There are two ways of treating and measuring a "force." (1) By the *pressure* it produces. This is a static action, and it measures a force as a *degree*, not as quantity. A force so regarded is an abstract property or power: it has no relation to energy, because it does no work; though it has a relation to *potential energy*. (2) By the motion it produces in matter, and this again has two aspects. 1. *Velocity*, which may be general or abstract, as in the case of the force of gravitation when expressed by the ordinary symbol g, meaning its capacity of generating a velocity of 32·2 feet per second. 2. *Momentum*, in which the force becomes concrete and *quantitative* by the introduction of unit mass of matter, and unit time. But this is no longer true *force*, it is an expression of *energy*,—of the work a force can do under unit conditions. The *dyne*, § 409, is such a force, or more truly a mathematical expression for a unit quantity of force, and it is the same value, in reality, as the *erg*, § 410, the unit of energy: they are simply expressions for the two aspects, *cause* and *effect*, force and work, which of necessity are equal.

483. *Gravitation* as a natural force therefore produces, 1, a static pressure, 2, a velocity (say 32 feet per sec.), 3, a momentum in a mass (say 16 foot lbs. per sec.). It also produces *acceleration*, § 409: that is to say, acting continuously, its effect is accumulative. This property would be important in a treatise on mechanics, but does not necessarily enter into the electric treatment of force; its effects are included in the actual velocity and momentum generated. But it may be well to point out that the ordinary conception of gravitation, as due to

the attraction of the earth for movable bodies, is misleading, because it leaves out of sight the part played by the second body itself. The effect of this is that while we can express a spring or steam force as a pressure of so many pounds per square inch, we cannot so express gravitation *per se.* We shall deal with such a pressure presently as "head of water," but this is a compound expression. Besides the attraction of the earth, it includes that of the water itself, that is, its own weight (or more properly mass). Of course it is perfectly known that this attraction is really that of the two masses, earth and body; it is only the common way of thinking that I refer to, which reacts even upon science. In our utter ignorance of the real cause of gravitation, we fix our ideas upon the mere masses of matter, and satisfy ourselves with the statement that it is $\frac{M \times M^1}{D^2}$, and in that formula we bury away the agency itself, the most perfect representation we can find in nature of an omnipresent consciousness. That formula, like the identical ones for electricity, § 86, and for magnetism, § 150, shows that these so-called quantities are really stresses or attractions exerted by forces.

484. We wind up a spring, and we know we have stored our work in it. We wind up a weight, and we know we have stored our work in it. We speak of "potential energy" in both cases, but in how different a manner do we think of the two agencies: one seems real and the other mythical: the one we call energy of *stress*, molecular strain; the other we call energy of *position*. But let us conceive a rope passing over a pulley, and thence to a winch by which a spring can be strained, or wound up. We have here a tangible agent to deal with. We see the strained spring, and we know that the spring, by virtue of that strain, will return us our energy by doing work equivalent to that employed in generating the *molecular stress.* But we replace the spring by a mere weight which we wind up, and then we talk of energy of position. It should be clearly realized that the two conditions are identical: in winding up the weight we have in some way, wholly unknown to us, put *a stress upon the earth* and stored energy just as certainly as in the spring. We do not know how, but in some way the force of gravitation is as surely an expression of energy stored up in matter, as is the attraction exerted between two electric charges or two magnetic poles.

485. The most convenient illustration of the mechanical effects of force, is to be found in "hydraulics," that is to say in the currents of water produced in pipes by the force of gravita-

tion, which force is expressed as "head of water;" that is to say, as the height of a column of water, supposed to have an unlimited supply, which is capable of producing the required effects; head of water is in fact the product of the attractions exerted between "earth" and each particle of water in the column, and therefore of the mass contained in say a column of unit area. But there are two difficulties in applying the illustration to electric currents. (1) Head of water, acting as a "mechanico-motive force," has the cumulative effect of "accelleration" which does not occur in electrical actions; (2) the friction, or true resistance (i. e. energy expended in maintaining current), is more complex in the case of water; it is, in fact, two-fold in origin; there is the friction within the mass of water, and there is the skin friction against the pipe, and these two do not increase in the same ratio: in electricity there is only one order of friction related simply to the square of the velocity of motion, i. e. as C^2.

486. The fundamental law of hydraulics, that is of "current" in the case of water, is that *the velocities* (that is currents) *are as the square root of the heads.* But the potential energy of a unit weight of water is *as the head* or height of the column through which it falls, and the result is that M or mechanical motive force corresponds to the square root of the potential energy, while E or electromotive force is directly as the energy, as will be seen in the Chapter on E M F.

487. *Current* therefore is, in electricity, a rate of action measurable chemically and magnetically, which is, by Ohm's laws, § 474, generated *in the ratio* of the E M F or potential (that is, as the energy available under the conditions of the source), and *inversely* as the so-called resistance, § 475, because this resistance is the arithmetical reciprocal of the conductance of the circuit, i. e. of its capacity to permit the action we call current.

488. *Resistance* becomes intelligible when thus considered, although it is an altogether different thing from what the term means in mechanics: the conception will be clear if we consider a conductor not as a whole, but in its components, as if built up of a number of unit conductors, all alike, side by side, and each passing equal current; that is each having *unit capacity* and offering *unit* resistance in the true sense of friction. It then becomes obvious that the law of transmission (alike for water and electricity), must be:—1. Current is as *capacity*; that is to say, in wires, as in pipes, directly as *sectional area*, which is as d^2, because the *square of the diameter* corresponds to the number of unit conductors of which the wire is built up. 2. Current is *inversely as resistance,* because the resistance is inversely as

capacity; the fewer the constituent or unit conductors, the less the capacity, or greater the resistance. 3. Resistance is as length, because doubling length doubles the true resistance by giving double work, and therefore halving the capacity or *conductance* of the circuits.

489. It is the same thing arithmetically, to *multiply by a value* or *divide by its reciprocal*, so that if we call *conductance* A and its *reciprocal* (that is 1 ÷ A) R, the result E × A is the same as E ÷ R, while the treating this reciprocal as the reality has the practical convenience of enabling us to use actual lengths of wire agreeing with the figures; but it should none the less be clearly understood that what are called "resistance measures" are truly *conductors*, and really measure nothing but the *conductance* of the wires, &c., with which they are compared.

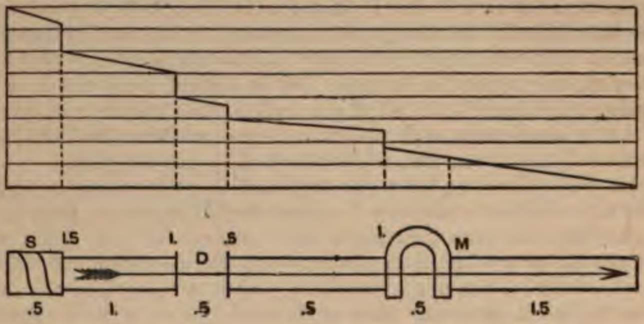
490. Here then we have the explanation of the common statement that electric resistance is equal for all currents, that is to say, an ohm is 1 ohm resistance for 1 ampere or 20. This, the first statement quoted, § 473, applies to the arithmetical value, the reciprocal; *for a unit conductor, pipe, or wire, has the same capacity for all currents;* that is, it will permit 1 unit current to pass under 1 unit force or 20 under 20 units. But none the less it will, *for both water and electricity*, retain "a certain amount of energy proportional to that transmitted:" and that is, *for electricity as for water*, in the ratio of the "square of the velocity of flow," i.e. as C^2.

491. *Electro-motive force*, or potential, is generated by the energy supplied to or by a "source" which sets up the current; it is manifested as a "pressure" measured in volts, and it may be conveniently called the *voltage* acting in a circuit. It is wholly expended within the circuit, either in overcoming resistance or in doing work by the circuit, which may be expressed as a resistance; or else it is neutralized by an opposing E M F. Therefore it disappears by degrees, as explained § 442, in what is often described as the slope of potential. It is a regular slope (as shown Fig. 49, p. 227) in a uniform circuit; but where a circuit is composed of varying materials and operations, it is more complex, and Fig. 58 will explain the facts.

The circuit is represented by the arrow traversing the source S, a voltameter D, and an electro-magnet M: the upper figures represent counter electromotive forces, and the lower figures show the resistances of the various parts. It will be seen that voltage expended in R forms the varying slope of potential, while voltage lost in meeting – E M F disappears in vertical lines.

The gross energy represents 8 volts shown vertically, of which 1·5 is absorbed in negative reactions, as explained in Chapter on E M F; a like amount, representing the energy of water decomposition is carried off by H and O in the voltameter, and 1 volt corresponds to mechanical work done by the magnet. The resistances of the several parts should amount to 4 ohms (but by oversight show 4·5), so that the conditions are those of a current of 1 ampere, by Ohm's law $E\ 8 - 4 \div R\ 4 = 1$ ampere. With any other than a 1-ampere current the expenditure of energy as C^2 would complicate the figures.

FIG. 58.



492. This diagram shows plainly how utterly unnecessary it is to go out of the conductor to look for the vehicle of the energy, and how perfectly the "common-sense theory" covers the whole ground. To show this it is necessary that the source S should represent a galvanic battery, because then the energy is derived from the circuit itself, and not from mechanical power acting through the agency of magnets; the same principle applies in all cases, but in the battery it is obvious. The genesis of E M F will be fully explained in the proper chapter: here it needs only to refer to pp. 101–5. The E M F is simply the energy of chemical action appearing in another form, and it *appears only in, and confined to the electric circuit.* It never becomes radiant like light or heat: this is no mere assertion, but a demonstrable fact. The energy may and does appear in two forms (see § 164): in one form it is set free at the zinc surface as *heat,* radiant energy which contributes nothing to E M F, and which never returns to the circuit, but is dissipated at the source itself; this is what is called local action. The other part constitutes E M F, and is traceable stage by stage *in the conductor only*, as in Fig. 58.

It is a mere wanton hypothesis to assert that this energy leaves the source "radiant like light," then "swirls round" without any new force applied, and distributes itself along the whole length of the conductor from outside space.

493. *The current* as well as the energy testifies to this: providing no leakage is permitted, the circuit may be opened at any part, even a thousand miles from the source; at every such section there will be found a chemical power (§ 469 *c*) exactly equivalent to that in the source: at every such point chemical energy (469 *d*) will be required, and supplied, variable with the natures of the particular actions. This is intelligible when we recognize the "current" as a molecular motion produced by the source, propagated through the conductor, and itself transmitting and expending the energy as required. It is utterly unintelligible if we consider that the current itself is set up by energy returning to the conductor from outer space.

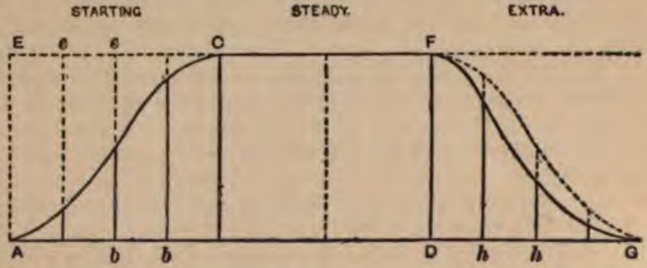
494. Then we have the magnetism around this circuit, equal through its whole length, and proportioned strictly to the current, while the energy is variable at every part, according to the varied nature of the material, and even its dimensions, and variable as the square of the current. No intelligible explanation has ever yet been offered (is one possible?) of the means by which this radiant energy, far away in space, recognizes and obeys the calls upon it from this conductor, which Dr. Lodge tells us "conducts nothing, not even an impulse." Is there in all nature a single instance of such action on the part of radiant energy under any known form? Does light ever turn back on, or aside from its path, unless some outside agent meets its rays? Yet we are told authoritatively that electric energy does so, although it leaves the source "radiant exactly as light is radiant."

495. Why have our leading professors been led away into these imaginations? Because there are some exceptional phenomena which occur at the setting up and cessation of true current, and they have invented these notions in order to make one explanation serve for two distinct orders of facts. It is the growing importance of "alternating currents" and the fact that they are not covered by the ordinary Ohm's formulæ (though perfectly subject to Ohm's law), which has led to the manufacture of an entirely new style of mathematical harness. A clear conception of the different functions of the *conductive* and *inductive* circuits (see p. 66) and a recognition of the fact that alternating currents (that is the induced currents) are not phenomena of the true conductive circuit, but of the *inductive circuit*, would have prevented our scientific men from

abandoning the true principles of modern science and reverting to the old "science, falsely so called"—the process of reasoning *à priori* from hypothetical data, instead of by induction from proved facts. But they must needs pretend to furnish explanations of things they could not understand, and the result is the endless invention of functions of the ether, about which they *know* absolutely nothing; the mere existence of which is a pure hypothesis, convenient but unprovable even in the case of light, but unnecessary in any other case, and drawing attention away from true knowledge.

496. Let us examine these phenomena of commencing and ending currents. Any process which is gradual can be represented by a curve, and Fig. 59 represents these facts.

Fig. 59.



The line A G is the period of a current, of which the circuit from the source is broken at the time D. The rising curve A C is the time of development of current, the period of *retardation* (see §109) C F is the period of constant current, in which the full E M F is acting and to which Ohm's formulæ relate; the falling curve F G is the "extra current" period, during which energy stored during the period A C in the inductive actions, returns to and becomes E M F in the conductor.

497. These two periods and the form of the curves depend upon the nature and arrangement of the circuits, i. e. upon the work that the source has to do before it is free to act in the conductor. In fact the energy of the source has at first several claims upon it, and has to satisfy them all in fair proportions, in other words it has to set up a series of *stresses*: let us consider two principal ones, as in §109, a closed conductor and a condenser; the first may have a resistance of 1 ohm and the other of millions, yet *current* in the one will rise only in exact proportion with *charge* in the other; in some sense the con-

denser acts as a leak in the conductor. We can conceive a mechanical analogue; we can exert a pull at a distance by means of a wire, such as bell-wire, but if we have a part of the wire replaced by a spiral spring, we can no longer exert that pull in full force *until we have satisfied the stresses of the spring*; if we give a series of pulls and releases, we no longer effect the same work at a distance; and at each impulse we store energy as stresses in the spring before we can transmit energy to the end of the conductor—the wire.

498. *There are stresses of three descriptions* to be produced in the electric circuit, which are analogous to this elasticity of what we may call the bell-wire circuit.

(*a*) The molecules of the conductor have to be set in motion, that motion which we call current, in order to constitute the lines of polarization. This implies that a momentum must be generated, in which energy is stored in opposition to the stresses or forces which exist in the ordinary condition of matter.

(*b*) The inductive circuit must be charged (see § 469 *f*, *g*) and this stores energy in very varying degree, according to the nature of the surroundings and the arrangement of the circuit.

(*c*) The magnetic powers of the circuit must be developed.

These several stresses are included together in the older phrases "self-induction" and "mutual-induction," and are now usually lumped together in the term "inductance." As they are all of them storages of energy, and measurable together in one unit, the henry, it may be right to have one inclusive term: but it is of the utmost importance to recognize the essential distinctions among the constituents, *momentum* in the conductor, *induction* in the static field, and *magnetance* in and around the conductor.

499. Returning to Fig. 59, the vertical line A'E is the E M F of the source, and as E M F involves two distinct lines of thought, pressure and energy, I think it will aid perception very much if we use different terms for these two aspects; *voltage* is now commonly used to indicate electric pressure, and I propose to use the term *voltance* for the quantity of energy which is the origin of E M F. The great value of this differentiation will be seen later on.

When a circuit is closed, the voltage acts upon all paths open to it and produces the stresses of § 498, and Fig. 59 is intended to add the inductive work to the mere current curve which is usually given.

The space inside or below the line A C shows the energy expended, the *voltance* transformed into heat, the *voltage* employed at each instant in producing current: the space outside the line, the dotted continuations of the lines of active E M F and current, show the *voltance* passing into the outer storers of energy, the inductance and magnetance.

Here we see the actual observed conditions, a transfer of energy into surrounding space and matter, but purely in the form of stresses set up against the ordinary forces of matter, with no action whatever outside the conductor (except work) as long as steady current continues.

500. Now circuit is broken; the pressure of the voltage no longer resists the ordinary forces of matter: these in turn become pressures or temporary voltage, in other words counter E M F gradually vanishing as things return to their normal state, and the stored voltance returns into the circuit, producing a continued vanishing current. But the final curve F G never fully equals the current lost in A C, because some energy is always expended in these outside operations, as shown in the dotted curve F G.

501. It may be well here to consider another matter which Fig. 59 makes very clear. If we place a good galvanometer in a circuit which can be broken at different rates, i. e. in which the *frequency* of intermittance can be varied, and of which the inductance can be varied, much is to be learnt. Many years ago I made such an experiment, using a cylinder mounted on a shaft driven by clockwork as the break, the outer surface being cut into a crown wheel, a spring pressing upon the continuous portion and another upon the teeth, which were of equal width to the spaces. Of course the effect is that the current only passes during exactly half the time, *no matter what the rate* of rotation, and therefore, using a somewhat heavy needle, though very free to move, the reading of current must be, from that cause, reduced to half what it would be were the break at rest, and full current passing.

But when the break acts the current reading lowers, not merely to half, but to a degree much greater, according to the speed, showing a new action besides the actual cessation of current. But now running at a fixed frequency, and having a steady current, let us alter the "inductance," let us connect different condensers which have nothing at all to do with the circuit, and down goes the current reading. Let part of the wire have been wound into a coil and insert iron into this; down goes the current. Of course these are but very crude illustrations of facts now well known, but probably many students would get from them much clearer ideas than they would from long dissertations upon "self induction."

502. *The etherial theory*, § 466, is said to be proved by these facts, and on the strength of them it is asserted that the current commences on the surface of the conductor (which is probably true, as explained § 506), and that it is produced, not by a stress from the source within the conductor, but by streams of energy entering the conductor from outside, and at once escaping out again as heat.

Sir W. Thomson says, "When the period is very small compared with 400 times the square of the smallest diameter, multiplied by its magnetic permeability and divided by its electric resistivity, the current is confined to an exceedingly thin surface stratum of the conductors," and moreover it is not proportioned to the conductance of the whole conductor, but to that of this thin stratum.

If the reader will make a copy of Fig. 59, fold it on itself on the dotted middle line, and pass it into a slit in a card, he will see the reason clearly: by drawing it into the card we alter the time or frequency, and when the lines C and F come together, we have a pure wave just equal to the full power of the source. As we continue to draw in, we increase the frequency and lower the wave (i.e. the current), and we can go on doing this till we have hardly any current at all in the conductor, though we may have plenty of actions external to it, in the form of "induced currents" and static phenomena.

503. HYDRAULIC ANALOGY OF CURRENT.—As stated § 485, there are some differences in the conditions relating to the flow of water in pipes and the transmission of electric current in wires, which must be taken into account when we trace out the strong analogy which exists between the two; that simply implies that, as in all other cases, we must distinguish analogy from identity, and while we may learn much in noting the points of resemblance, we must clearly see the differences which exist. The true analogy is not with such a system of pipes as we have for supply of water. The water leaves these, which electricity does not, and it carries energy away with it: the difference in the nature of the frictional resistance is mentioned § 485, and this affects all cases; but the true analogue is to be found in the hydraulic systems for transmitting power and doing work. Here we have a closed circuit in which the water circulates, closely resembling the electric circuit, in which the engine and pump correspond to a galvanic battery. We have not only the water circulating without diminution, as is the case with electricity, and serving as the agent for conveying energy, but we have + and − pressures in the pipes shown by gauges, just as the electrometer shows them in the circuit, and we have a "slope of

potential," a gradual expenditure of energy and accompanying loss of pressure, identical with those of electricity shown in Fig. 58.

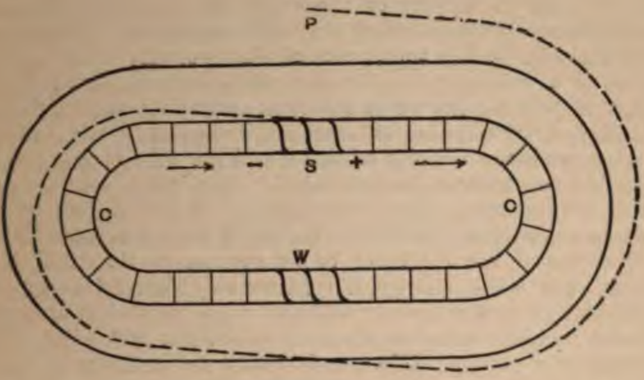
504. But we have nothing to correspond with the inductance and magnetance of the electric circuit, and we have the momentum element largely increased. It was the same with electric currents at first; it was only when telegraph cables began to be used that "retardation" was noticed, and only when coils for producing induced currents became of interest that the inductance of electric circuits was studied. Hydraulic circuits as practically used, composed of rigid steel pipes, do not introduce the corresponding conditions which, as shown § 497, would involve *elasticity* in the conductor or pipes. This would be a serious practical evil, though the accumulator does really introduce something of the sort, just as the fly-wheel does in machinery, for in both of these a resistance is introduced to absorb energy, which is given up when the source acts less strongly.

We can, however, introduce this element for the purposes of theory. We need only to conceive a strong indiarubber pipe used in place of the rigid metal, in which a certain amount of expansion, proportioned to the pressure and to the elasticity of the pipe, would accompany the propagation of current, and maintain an "extra current" when the source ceased to operate: the conditions then are perfectly analogous to those of an electric circuit, although the process in one case is purely mechanical, while in the other it is molecular.

505. These conditions are shown in Fig. 60. C is the pipe in which is inserted the source S, a turbine to set up a current in the pipe, drawing the water in on the − side and forcing it out at +. W is a similar turbine driven by the current and doing external work, corresponding to either a decomposition cell or magnet of other illustrations. Each revolution of S sets in motion a unit volume of water, which traverses every section of the pipe, with velocities varying according to the cross sections, when these are unequal, exactly as in the electric circuit; in neither case is the quantitative element, water or electricity, expended or converted into work: the turbine W, would be set in motion, and we commonly say that it is driven by the water, and truly, in the same sense that wood is cut by a knife; but in reality it is neither the water nor the knife which acts; they are simply modes by which *energy* is enabled to act: in like manner electric current does nothing itself (except as regards chemical actions where the molecular breaking up is a function of the current itself) but it transmits and applies the energy derived from the source.

The full line surrounding the circuit is intended to represent an initial pressure put upon the pipe to enable it to contract as well as expand; it corresponds to zero potential in the electric circuit. When the source operates, this line of pressure is converted into a "slope of pressure" in the dotted line P, which exactly corresponds to the "slope of potential" in electricity, and is really variable according to the conditions of the circuit, exactly as shown in Fig. 58 for electric current. The hydraulic circuit corresponds in every way with the electric circuit; it may be subdivided into many courses, each doing its particular work, and these will in all respects resemble "derived circuits" in electricity, and act as described in §§ 442–448; and the turbine S corresponds to the zinc surface in a battery, sending energy into the circuit by means of a "current" distributing stresses: like the cells of a battery also, this source may be subdivided; instead of one powerful turbine, several may be used, and may be joined up in "arc," increasing flux but not pressure, or in "series," increasing pressure but not flux, except as a consequence of the pressure, the number of revolutions agreeing with the chemical equivalent actions in all respects.

FIG. 60.



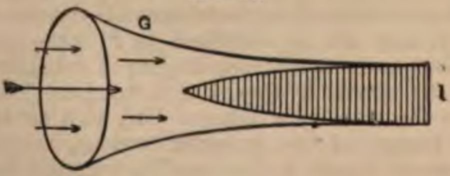
506. We may now find in the hydraulic circuit the very phenomena described § 502. The first action of the source is to set up a pressure in one direction, and a suction or − pressure in the other, the two uniting to produce the direct motion of current in the water and the opposite curves in the elastic conductor of Fig. 60. But this takes time, and we have to consider conditions of the "variable" period such as produce

the rising wave of Fig. 59. There is the inertia of the water to overcome, and also the expansion of the pipe to be effected. The first action would suck water from the − side of the source and force it to the + side; there would be a local current close to the source, but none in the circuit. Now this is just what happens in the electric circuit. If a long submarine cable is coiled in a tank full of water, a current may be sent in at one end and may not appear at the other for some seconds; nay, several successive momentary currents may be sent in, and will leave the other end in succession, as waves or impulses.

This is a crushing fact for the new doctrines § 466; if the energy travels *viâ* the outer medium, producing the current as an action from outside, as asserted, it has only the tank to traverse, with the velocity of light, and the wire is everywhere accessible to serve as the pretended "sink"; the action ought to be instantaneous. The "retardation" is intelligible on the common-sense theory, that the action is wholly effected by the conductor, and has therefore to be limited by its small cross section, while the energy is continuously drained away into the inductive and magnetic fields, so that current is only propagated in the conductor when these are charged, after which they make no further claims, and steady current goes on unimpeded, and equivalent to the whole of the energy which the source can supply under the conditions of conductance.

507. These phenomena are illustrated by Fig. 61. G shows the pipe expanding under pressure transmitted gradually as the inertia of the water, shown by the shaded portion *i*, is overcome: this will obviously result in the double cones shown and in a *mere skin current* preceding the formation of true current just as stated by Sir W. Thomson, § 502. But this does not result from energy *entering from outside*: the energy is within, but there is also a resistance within and an outlet and claim from without, and these result in the phenomena observed, as in the case of the cable in the tank. The new notions are mere wanton assumptions, and they cannot stop at electric

Fig. 61.



currents: the theorists will have to maintain that hydraulic pipes, machine shafts and belting, do not transmit energy, but only serve as sinks. We are getting near to this when they claim that the ether is the real storehouse of energy, and that "coal must be regarded as a mere machine for extracting energy from the ether." Into such quagmires of thought men must be led who follow the will-o'-the-wisps of hypothesis, instead of the safe light of knowledge and experimental fact.

508. *Induced currents* will be treated under the head of electromagnetism, but their fundamental facts may be examined here as part of the same theoretical subject. When a current appears in a conductor not connected to a source, what is its origin? This involves two considerations: the *current*, which in this case is not derived from the source, but is generated by an action from outside; and the energy, which, both as a fact and by the law of the conservation of energy, is derived from the source and is transmitted by no obvious agent to the separate circuit.

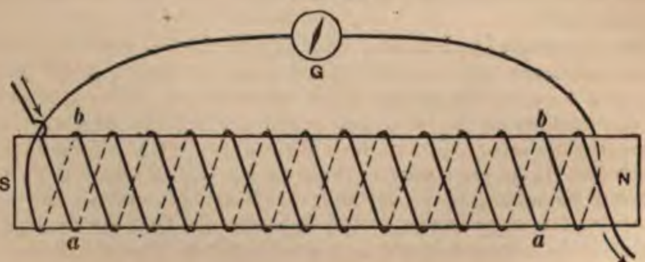
This ought to be clearly understood, because it is the one bit of fact which the new theorists offer as evidence. In a discussion in the "Electrician" upon the subject with me, Prof. Silvanus P. Thompson says, vol. xxvii. p. 44, "I propose to show that there are certain cases in which, beyond contest, the energy is transferred from the source to the work across the medium. I shall show this where there is no metallic or other conductor which can possibly effect a longitudinal transfer, and in which therefore the transfer is lateral." His argument is that, as such cases are certain, "one is logically driven to the conclusion that in all cases the mode of transfer is the same."

The argument is plausible, but fails wholly for three reasons: (1) the assumed sequence is not a logical necessity, as we have no right to assert that there can be only one *modus operandi*; (2) the conditions in the two cases are wholly different, for where the transfer exists no flux is produced, only a momentary action due to stress: where there is continuous action of the source it is admitted by all that there is no evidence of any transfer of energy in space, and it is certain that no current is produced in any conductor not connected to the source; (3), and most important, there is no evidence *at any time* of transfer, of energy direct *from the source*. Prof. Silvanus P. Thompson gave a number of illustrations, in every one of which the energy was obviously derived from a conductive circuit, and not by any radiant action from the source direct. In fact there is no single case in which there is any reason to suppose the energy or influence reaches the work except by the agency of a closed conductive circuit. Even in the case of the Hertz experiments, which are so often asserted to prove the new theories, the very opposite is the truth; the action never proceeds from the "source" of energy, but always through intermediate apparatus which sets up conditions of *inductance* and *magnetance* around a conductor: the Hertz experiments relate to phenomena of inductance; ordinary induced currents are phenomena of magnetance; but both are only momentary consequences of the "variable period."

509. Prof. Thompson's principal argument relates to a coil of wire A connected to a source, and a similar coil of wire B parallel to it connected to a galvanometer: as we all know, current is produced in B when circuit is closed or broken in A, and in some way or other energy has passed—not from the source to B, but from A to B. Now what is the mode of transfer? Let us place B in some position not parallel to A, say at right angles: this change in no way alters its relation to the "source" or its position among the imaginary "rays" of energy, but it instantly stops the action. Now pass a curved piece of iron through the two coils, and action appears again more strongly than before. Here we have by actual experiment tracked the course of energy transfer, *not to the space between the source and* B, but to the magnetic functions of the conductor A; we have action in B when, and only when, the magnetic circuit set up by A threads the coil B.

510. We have precisely the same principles at work in Fig. 62,

FIG. 62.



which is a diagram of an induction coil or transformer: the two coils, *a* connected to the source, the primary conductor, *b* the separate secondary wire connected to a galvanometer, wound parallel to *a* upon a cylinder N S: the coils are just as distinct as if they were on separate cores.

Every one knows that when circuit is closed in *a*, a momentary current in the opposite direction forms in *b*; at break in *a*, a momentary current is produced in *b* in the same direction as the primary current; but as long as steady current continues in *a* no sign of current is found in *b*, but the whole energy is found as heat in *a*. Now is it possible that the energy comes from the source, entering the conductor *a* from outside and producing current in *a* as a mere sink? If so, why does it not avail itself of *b* also? *b* is an even better sink than *a*, it is a constantly closed circuit; it can turn this wandering energy into heat just as well as *a* can. How does this energy, radiant exactly as light is, distinguish between these two sinks? Why does it go only to the conductor (which conducts not even an impulse) connected to the source? Surely if the current is a product of the energy seeking dissipation in the "medium," both wires would be utilized.

The real explanation is to be easily found: the current is generated in *a* by the actions described §492; an essential accompaniment of current is magnetism around it; this is concentrated as magnetic lines of force in N S, completed in closed circuits outside the coil: all the space and matter around N S is influenced, and becomes magnetically polarized; but equally an inevitable accompaniment of magnetic polarization is the formation of electric polarity at right angles to the magnetic. Now the wire *b* is a closed electric circuit at right angles to the magnetic polarity of N S, and of necessity a momentary current accompanies the act of polarization, and ceases when that action is completed, although the stress which produces it is sustained: current is a phenomenon of molecular *motions*, not of mere stresses, of stresses only while they produce motion. When the stress ceases, the ordinary forces of matter reverse the motion, and the energy charged in the stress passes into any available conductor (in this case really a sink) in which current can be generated. In Fig. 62 it so happens that the coil *b* is parallel to *a*, but that is a mere incident; as seen § 509 the thing of consequence is that it is at right angles to N S. Let N S be a ring and the coils *a*, *b*, may be in any position whatever as regards each other, so long as both are at right angles to N S, which carries the energy issuing from *a* to charge the magnetance of N S, a part of which magnetance is the production of electric current where suitable conditions exist.

511. INDUCED HYDRAULIC CURRENTS.—It is important to note that we can reproduce all this in the hydraulic circuit. Let us place two such circuits, as shown Fig. 60, in a closed case which presses them together; one, A, containing the source, the other,

B, containing the working turbine. Directly A assumes the taper form, B will be forced into the same taper, reversed as in electricity, and a momentary current will flow, ceasing as long as steady stress is maintained in A. When the source ceases to act, the elasticity of the pipes, the analogue of inductance, will cause a temporary current to flow in both pipes. By intermitting repeated actions of this kind, a series of alternating currents could be produced, with all the effects of "oscillation" and the other phenomena which are familiar in electrical circuits. Corresponding instruments, such as commutators, would be needed to deal with such currents and enable them to do work, and the difference would be merely the rate of "frequency" due to the momentum of water and dense matter.

512. It is the same with the experiments of Hertz. Here we have two circuits, A, a circuit from the secondary of a coil (such as Fig. 62), in which energy circulates as momentary stresses set up and ceasing; in this circuit are placed two condenser plates, one on each side of the spark space. These of course set up the conditions of charge all around them, §105. Another pair of plates is placed opposite them with a spark space, and of course these second pair form part of the lines of induction of the first pair, and take part of the energy: hence momentary currents set up between them; the question of undulation as the mode of transmission of energy and the "nodes" &c., discovered by Hertz, the really novel part of his experiments, will be considered later on; here we have only to note that the currents in the secondary pair are merely an illustration of long known facts in induction. The case resembles the magnetic lines of force; if we draw two magnetic poles placed like the Hertz "inductors," we know and can show the curves extending into space between them: if on these curves we place a rod of iron, we know it is magnetized by induction whenever the primary magnet is energized; we could place two such pieces near each other on a curve and show N and S poles developed at the space, and magnetic force existing in that space. The Hertz "resonator," so called, fulfils the exact function of the two pieces of iron, only it forms part of a line of force of electric inductance, and shows electric force in its spark space, in the same identical manner and for the same physical reasons as the pieces of iron manifest magnetic lines of force and do work in a magnetic field. There is no mysterious agency, except so far as every natural action is a mystery of which we can see the manifestation, but never the cause; there is nothing more than some actions of energy and matter long studied under the name of "induction."

CHAPTER VII.

CONDUCTIVITY AND RESISTANCE.

513. These terms are the converse of each other, but there is this important difference—*Resistance* is absolute and measurable in standard or other definite units. *Conductivity* is only relative or abstract; though it is usually stated as relative to copper as a standard, still this is only relative, as it fixes no dimensions. Conductivity is ascertained by measuring the actual resistance in a given case; then by calculating what would be the resistance of pure copper in like conditions, we obtain the relative conductivity of the substance examined.

514. SPECIFIC CONDUCTIVITY.—Under the same conditions of dimension, different substances have different capacities for transmitting current; that is to say, different molecules differ in their relation to electricity as they do to heat. But this is not, as in the case of heat, connected to the atomic weights of the substances, or to any as yet discovered physical property; so far as we know it is a special property of each substance. This relation is most easily measured as a "resistance" of a fixed dimension: a unit of dimension, now much employed in connection with the C G S system, is 1 cubic centimetre, used as in Col. III. of the Table of Resistances, p. 273, where "specific resistance" is given in the C G S units of resistance per cubic centimetre of the substance. This is useful with liquids and insulators whose resistance is large, but as relates to metals and to those using only the ohm unit it conveys little meaning, and the familiar form of a wire best conveys the facts to the mind.

A wire either of definite dimensions, such as 1 foot length, ·001 of inch diameter (conveniently call a *mil*, which must not be confused with the millimetre), is a very practical unit, which has the scientific merit of illustrating very clearly the part which *matter* plays in conduction, and distinguishing the properties of different kinds of matter.

For practical purposes, as where we have to deal almost entirely with one metal, copper, for some purpose a wire 1 foot in length and weighing 1 grain has its uses. These units will be employed here, and the Table, p. 273, derived chiefly from the labours of Mathiessen, gives the most important particulars employed by electricians. Col. II. is the specific conductivity referred to silver as 100. The cubic centimetre corresponds to the similar unit, the square millimetre, 1 metre long, which is generated by multiplying the centimetre cube by 10,000.

515. *Alloys* usually have a higher resistance than that of the mean of their components, which appears to indicate that an actual chemical combination has occurred, not a mere mixture of the metals. This property even affords a means of classifying alloys as of these two orders. Thus the alloys of tin and lead differ slightly from the mean, while that of tin and antimony has only $\frac{1}{30}$th of the mean conductivity, indicating a much closer combination. Other physical properties attend this classification. I have even found that the specific resistance of a wire affords an approximate test of its constitution. Thus the resistance of German silver wire, reduced to the foot grain, varies from 2·60 ohms to 4·09, according to the proportion of nickel it contains, that of pure copper being ·219 only.

Alloys are also affected by heat, as to their conductivity, differently from pure metals, which it will be seen renders some of them very useful. Particulars are given in Table IX., below the pure metals, of a few of the most useful alloys. As a consequence, ordinary commercial metals (which are always alloyed with foreign matters) have a higher resistance than pure metals, a fact of great importance as regards copper, § 548.

All experiments, so far, indicate that the electric current does not separate the constituents of either alloys or amalgams, by electrolysis when in a state of fusion.

516. HARDNESS generally increases the resistance of metals; this shows that transmission of electricity depends upon molecular condition, for hardness is a state of stronger cohesion and less freedom of motion. Annealing diminishes this strain, and allows readier motion of the molecules among themselves. As time and the passage of electric current produce softening, it is important to use soft wires where resistance is to be constant, and where it is required to be low, as in galvanometers. Soft wire is also more easily arranged.

Mechanical Stresses, such as torsion or tension, modify conductivity, as also does *magnetism* in the case of iron or steel. *Bismuth* also increases in resistance when placed in a magnetic field, and a thin spiral of it has been suggested as a means of measuring the strength of such fields by this increase, as the increasing resistance of platinum due to heat is employed in pyrometers.

517. *The conductivity of metals for heat and electricity* is practi-

cally alike, in degree that is, not as to actual rate of conduction: this is a very strong indication that the mode of transmission is, for both forces, a specific molecular motion graduated by the special nature of the substances.

Variation of temperature has a remarkable influence on the conductivity of bodies. As a rule, the resistance of liquids diminishes as the temperature rises, while that of metals increases. The influence on pure metals is nearly uniform, not as regards their actual, but their relative resistance. Thus whether a metal have a high or low specific resistance, that resistance increases in almost exactly the same ratio—for instance, bismuth and copper. The slight differences shown in the Table, Column VIII. are probably due to some impurity in the metals, which are not readily obtained in perfect purity.

Mercury, however, is an exception, owing to its liquid condition, no doubt; and its slight variation is an additional element of advantage in treating it as a standard for units.

But *alloys* differ from pure metals in being much less affected by change of temperature, which, together with their greater resistance, renders them suitable for measures.

Carbon or Graphite lowers in resistance by heat, so that incandescent lamps pass larger current as they heat.

As the current itself heats the wire, it varies the resistance as though the heat were external; and it is important to use a low power in measuring resistances. The mode of correction for temperature is given in § 533.

It would appear that the resistance of metals is related to the absolute zero of temperature.

518. LIGHT AND CONDUCTIVITY. *Selenium* in its ordinary state has very little conductivity, but when kept just under fusing point (220° C.) for some hours, and slowly cooled, it assumes a crystalline condition, in which its resistance is greatly lowered, and becomes variable under the influence of light. In some cases it is fifteen times greater in the dark than in sunlight. This variation is also so rapid that it produces sound in a telephone under the influence of an intermittent ray of light. Other substances undergo similar changes, but this subject will be dealt with in another chapter.

519. CONDUCTANCE.—This is a convenient term now generally used to express the *conducting capacity* of a circuit under the conditions of the moment; it is often said to be the reciprocal of the resistance, because the conception of resistance in measured units was first clearly defined, but in principle the reverse is the case; the conductance is the real fact, the resistance a mathematical artifice, as explained § 475. Sir W.

Thomson proposed to express it in a unit—the mho—which is the inverse of ohm, but the term does not find favour.

520. RESISTANCE.—It has been shown that this term includes two distinct conceptions: (1) the arithmetical expression—the reciprocal of the conductance; (2) the energy expended by the current. It is of great importance to keep this distinction clearly in view, for the law of sectional area or diameter of a conductor is related only to the first conception, while most of the other facts of resistance relate to energy expended. The clearest conception of the whole subject will be attained by fixing the ideas upon the single molecular chain, transmitting a unit electric current, as shown p. 259, and picturing conductors as built up of separate unit chains as explained § 488.

The OHM, 10^9 C G S units, § 419, is the measure of resistance, represented by 106·3 centimetres of pure mercury at 0° C. of 1 square millimetre section. The *B.A. unit*, the original standard, is now found to be equal to ohm ·9866, and 1 new ohm is 1·01351 B.A. units.

521. But as nearly all existing instruments have been adjusted to the B.A. unit (then called the ohm), and the Post Office continues to use that standard, having, in common with every one but a few Professors, refused to have anything to do with the so-called "legal ohm," it is probable that this will remain in use for many years, being corrected by the above constant. Resistance instruments are too costly to either throw aside or re-adjust, and we must look forward to some considerable confusion for a time.

All the values given in this chapter *relate to the B.A. unit*, and need multiplying by ·9866 = log $\bar{1}$·9941411 to convert them into the new ohms. I have not recalculated the values, because several things connected with them are not yet definitely ascertained, and these tables being stereotyped, this labour and expense are deferred until the actual values can be relied upon as final. See § 417.

522. *Resistance* is often said to be *a velocity*. The statement conveys little or no idea to most minds, and in fact in this form it has no meaning; it is a part of the artificial system of mathematical electricity. Dr. Lodge will not be suspected of heresy on this subject, and he says, "It is sometimes asserted that an ohm is a velocity, by those who ignore the fact that it is only a velocity on a conventional system, yet nothing of the kind is connoted by the term." The conventional system is that of "Dimensions," § 415, and the dimensions of resistance are $L^{-1}T$ on the electrostatic system and LT^{-1} on the electro-magnetic; that is to say, the expressions for all these units are different under different

conventions, though the thing itself is the same: this discrepancy is much more striking in some other cases, but it shows how careful the student should be not to make the common mistake of supposing that mathematical symbols represent, of necessity, any actual truth. These "dimensions" showing motion in time, correspond to *velocity*; but the "electrical resistance" is a mere creation of Ohm's formulæ, and expresses simply "the ratio of the energy dissipated per second to the mean square of the current," and may be considered as an obstruction which expends energy in an irreversible operation.

523. *Impedance* is a useful term, one of many devised by Mr. O. Heaviside; it is now adopted and represents *resistance proper + temporary resistance:* that is, it includes with the irreversible energy of resistance, the reversible stored energy of inductance, § 498, and it is measured in terms of the "henry," § 430. Impedance relates only to intermittent and alternating currents, and the phenomena mentioned § 501, and is the ratio of the effective E M F to the effective current, § 431.

524. Some of the researches of Dr. Lodge into the phenomena of lightning (or, to be correct, artificial lightning in the form of oscillating discharges from Leyden jars) illustrate the need of realizing these functions of impedance. He found that with very great "frequency" ordinary resistance was of little moment, and that the material of a conductor, as copper or iron, made no difference. He says, "The impedance of a conductor 2½ metres long bent into a circle was

180 ohms for thick wire No. 2 } at 12 millions
300 ohms „ thin „ No. 40 } per second,

the ordinary R being ·004 ohms for thick and 2·6 for thin.

43 ohms for thick } at 3 millions.
78 „ „ thin }

at a quarter million the material begins to matter."

525. Resistance and Work.—If an electro-magnet be excited by a battery, a current will pass proportioned to the E M F and to the measured R, and the expenditure of energy will be measured by $C^2 \times R$. Now give the magnet "work" to do, as in rotating an armature.

1. The current will be reduced.
2. The expenditure of energy will be greater than $C^2 \times R$, or $E \times C$ will show.

This extra expenditure of energy can be treated as an additional R caused by inductance, and the sum of these becomes "Impedance" which replaces R in Ohm's formula.

The value of work as R may be calculated by measuring C, and also E between the two parts of the circuit which contain the work, and of which R is measured while not working: then E × C × J (§ 426) gives the whole energy expended, and $C^2 \times R \times J$ that consumed in the R of the circuit: also E ÷ C gives the gross R (the impedance), which by deducting the measured R gives the equivalent resistance of the work.

526. A *counter-electromotive force* may often be measured as a resistance in the bridge or differential galvanometer, and balanced by a length of wire or measured resistance; but this measure *will not be constant for all currents* as an ordinary resistance is.

Inductance, static and magnetic, § 489, which store energy and give it up in the extra current, act as such a – E M F, and may (when work is not being done) be calculated from the current, for as C is as E, when resistance is unchanged, the observed C and measured R give the effective E by C ÷ R, and this deducted from the E operating in the circuit gives the $-e$ set up by the re-action.

527. CONSECUTIVE RESISTANCES.—Each portion of the circuit, i. e. the various cells of a battery, the connecting wires, any instruments used or work done, having each their separate resistances measured or known, these are added together to form the total resistance of the circuit. *It is only* this total which can be directly calculated by Ohm's formula, but the various external resistances may be ascertained by that formula, by the variation of the current as each is added to the circuit. For the internal resistance of batteries, see, § 531.

528. DERIVED CIRCUITS, see § 444.—When the current divides into two or more branches for a part of its course, the joint resistance of the united circuit is ascertained by the following formulæ, the separate resistances being first ascertained by the usual processes:—

(1) $\frac{A \times B}{A + B} = R$. The joint resistance is the product of the two resistances divided by their sum. Thus

$$\frac{\cdot 39 \times \cdot 64}{\cdot 39 + \cdot 64} = \frac{\cdot 2496}{1 \cdot 03} = \cdot 242.$$

When there are more than two paths, having obtained the joint resistance of two, this is used with another in the same manner. Let C be another such path having a resistance 1·9, then

$$\frac{\cdot 242 \times 1 \cdot 9}{\cdot 242 + 1 \cdot 9} = \frac{\cdot 4598}{2 \cdot 142} = \cdot 215.$$

(2) It is more easy to obtain the joint resistance by means of a table of reciprocals, the sum of the reciprocals of the separate resistances being the reciprocal of the joint resistance. (The reciprocal of a number is 1 divided by it; tables of reciprocals are given in many books.)

A = ·39	reciprocal	2·564
B = ·64	"	1·562
C = 1·9	"	0·526
Joint resistance	.. .. ..	4·652 = ·214.

This is, in fact, adding together the conductances in mhos, § 519.

(3) Another plan may be derived from the system of wire resistance, § 468. If we reduce each resistance to the terms of the area of a copper wire of 1, 10, or more feet, the sum of these areas represents a wire equivalent to the joint resistance.

529. SHUNTS.—These are derived circuits, § 528, and the term is derived from the railway process of *shunting* a train on to a second set of rails. Of course any wire led across connections acts as a shunt for just such part of the current as equals the ratio of the resistance, and therefore a second resistance instrument serves the purpose; but it is more convenient to prepare a special wire, equal to the known resistance of the galvanometer or other instruments it is to be used with, and label it with the purpose it is made for.

For other occasions, shunts are required bearing a known ratio, ½, 1-10th, 1-100th, &c., of the circuit they are to be used with. The following formula gives the proportionate resistance in such cases. R is the resistance of the instrument whose indications we desire to multiply, *n* the multiplying ratio, and S the resistance to be given to the shunt;—

$$S = \frac{R}{n - 1} \quad \text{ex.} \quad \frac{53}{100 - 1} = \cdot 5353$$

Of course the addition of a shunt to any portion of a circuit lowers the resistance and increases the current, unless an extra resistance is inserted somewhere else to compensate for the shunt, just as the insertion of a galvanometer to measure a current lowers the current previously passing.

Shunts should be made of the same material as the circuit they are used with, so as not to have their ratios disturbed by external temperature, § 517.

It is impossible to avoid the effects of self-heating by the current: in order to have the same action in both circuits the wire of the shunt ought to increase in weight in the same ratio as the current it carries; but for obvious reasons of economy and convenience this cannot be done. In fact the reverse is nearly always the case, a thinner and shorter wire being used instead of a thicker and longer. Therefore no shunts supplied with galvanometers can be relied on if more than momentary currents are passed through them.

530. *Cells of a Battery* are derived circuits to each other when they are coupled in parallel or multiple arc, and they divide the current upon the principles explained § 528.

Cells to be coupled in multiple arc may be of various sizes, but must be all of the same kind and of equal E M F; the stronger cells reverse the current of the weaker, and less current passes to the external circuit than if the weaker cell were not used, and yet the stronger cell is more rapidly exhausted. Zinc may also be deposited on the negative plate of the weaker cell, if it is a single liquid cell. So also when a number of cells are arranged in sets in series, and then coupled in multiple arc, all of the sets in one coupling must contain the same number of cells, so that, when in multiple arc, each branch may have the same E M F. In this way cells of different sizes and forces may be used in one circuit, and combined in both ways for small resistance (multiple arc) and high E M F (in series).

531. *Internal Resistance of Cells.*—This is subject to the same laws as wires, but depends on the specific conductivity of the liquids contained, and varies therefore during work, as the acids become converted into salts, &c.

MEASUREMENT OF INTERNAL RESISTANCE OF BATTERIES.

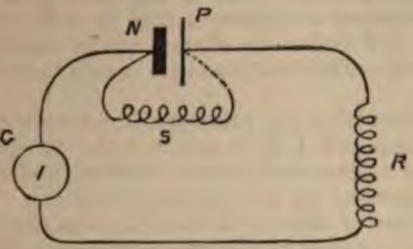
(1) *By Ohm's Formula.*—$E \div C = R$. This is the total resistance, and deducting the external gives the internal.

(2) *By the Galvanometer.*—With any known resistance produce a deflection; add resistance which produces a deflection of just half the current value of the first; this implies that the second extra resistance is exactly the same as the total of the first; therefore it is only necessary to deduct the known, or external resistance of the first deflection from that of the second: the residue is the internal resistance of the battery, together with that of any connecting wires not included in the first external resistance.

(3) *By a Shunt.*—Prepare a shunt of a resistance exactly equal

to the sum of all the other external resistances—viz. the galvanometer, and all the connections (and if any work is doing, the resistance of that also). Fig. 63 will now make all plain.

FIG. 63.



First connect as shown, so that the current divides itself through the two equal resistances, (1) S, the shunt, (2) G, the galvanometer, and R, the resistance instrument. Note the deflection carefully and then disconnect the shunt S; the whole current now passes through the other circuit; the *external* resistance is now doubled, because, by the laws of derived circuits, the resistance of two equal circuits together is half that of either alone, but the *internal* resistance of N P remains unchanged. Now add resistance at R till the same deflection as at first is produced in G. This extra resistance is equal to the internal resistance of N P.

Methods 2 and 3 have the disadvantage that with many forms of battery the E M F varies with the rate of current, so that the conditions are different at the time of the two measures.

(4) *Mance's method* avoids this, and enables the resistance corresponding to any rate or density of current to be measured. It is a modification of the Wheatstone bridge, and will be understood by a reference to Fig. 51, p. 228. Insert the battery to be measured in C and a resistance measure in A as usual: no external battery is used, but a contact break replaces it. If the double break, Fig. 54, is on the bridge, spring 3 should be fixed down upon stud 4 to keep the galvanometer circuit closed, and the ordinary battery connections, as + − Fig. 56 connected with a wire, when the upper pair of springs will act as the required break. It will be seen that the current from the battery in C, Fig. 51, has now two circuits from F, one through the galvanometer and the other through D B, both uniting at E and returning to C through A. If A × D = B × C, the

closing of the external contact will make no change in the reading on the galvanometer, through which, in this use of the bridge, current is always passing.

The resistance of a galvanometer can be measured in this way by its own reading, if placed in C, and the battery as usual in the external circuit. This is the usual form of using the bridge, but requires no galvanometer in E F. When closing the break in E F makes no change of the reading in the galvanometer in C. The resistance in A equals that of the galvanometer.

There are several other processes, but they require formulæ and calculations, and I have selected the foregoing modes of measuring the resistance of batteries as the simplest in principle, most readily performed, and accurate in results.

532. *Resistance of Metals.*—Table IX. gives the values derived from Mathiessen's measures taken in connection with the preparation of the original ohm. Later determinations differ, and a set by Benoit may be found, p. 112, vol. iv. of the 'Journal of the Society of Telegraphic Engineers;' but Mathiessen's values are generally received, and his well-known care and the means at his disposal justify the retention of his values.

Different figures are given in various books, and the specific gravities and resistances are not too certainly known yet. But as it is absurd to give discordant values in one table, I have calculated them from the two values of Cols. VI. and VII.; should any other values be deemed more accurate, there will be no difficulty in altering the whole range of values, which are physically dependent on each other. As mentioned § 521 these figures relate to the B A unit, not to the newly defined ohm.

Col. III. is the *specific resistance*, § 514, that of 1 cubic centimetre expressed in microhms. By shifting the decimal point 6 places to the left it becomes ohms, and by shifting it 3 places to the right it becomes C G S units: thus copper = 1·652 microhms, ·000001652 ohms, and 1652 C G S units. Microhms are convenient for metals, ohms for liquids, and megohms for dielectrics. See also § 514.

The line of carbon is derived from my own experiments, and relates to the artificial carbons, such as are prepared for the Jablohkoff candles and arc lamps. The specific gravity is probably greater in the carbon of incandescent lamps, but it is scarcely possible to measure it, as the adhering film of air prevents its being properly weighed in water. It is probable also that the specific resistance is lower, but to discover this, either the specific gravity must be known, or the diameter, which is equally difficult to measure experimentally.

TABLE IX.—CONDUCTIVITY AND RESISTANCE OF METALS.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.
Metals Pure.	Specific		Conductivity silver = 100.		Resistance at 32° Fahr. of 1 ft. of wire		Variation per cent. 1° Fahr.
	Gravity = s.	Resistance, Microhms = R	Weight.	Section.	weighing 1 grain. = U	of 1 mil diameter. = u	
Aluminum ..	2·574	2·944	204·05	51·67	·1085	17·72	..
Antimony ..	6·725	35·907	6·41	4·24	3·456	216·00	·216
Bismuth	9·817	132·658	1·19	1·15	18·64	798·	·196
Copper, hard ..	8·905	1·652	105·13	92·06	·2106	9·940	..
„ soft ..	8·927	1·616	107·27	94·17	·2064	9·718	·215
Gold, soft	19·639	2·081	37·853	73·09	·5849	12·52	·202
Iron, soft	7·781	9·825	20·18	15·63	1·097	59·10	..
Lead, pressed ..	11·392	19·847	6·84	7·65	3·236	119·39	·215
Mercury	13·598	96·185	1·18	1·58	18·720	578·60	·040
Nickel	8·513	12·579	14·42	12·08	1·535	75·78	..
Platinum, soft ..	21·437	9·158	7·88	16·56	2·810	55·09	..
Silver, hard ..	10·241	1·652	91·45	92·10	·2421	9·936	·209
„ soft ..	10·168	1·521	100·	100·	·2214	9·151	..
Tin, pressed ..	7·284	13·359	15·86	11·39	1·396	80·36	·202
Zinc, pressed ..	7·162	5·689	37·97	26·74	·5831	34·22	·202
Alloys.							
Brass .. about	8·4	8·266	22·18	18·45	·9938	49·72	..
German silver „	8·754	21·165	8·35	7·19	2·652	127·32	·024
1 Silver, 2 Plat.	12·021	24·661	5·22	6·17	4·243	148·35	·017
1 Silver, 2 Gold	15·203	10·988	9·26	13·84	2·391	66·10	·036
Carbon .. about	1·6	4196·	·2303	·0363	96·080	25240·	–·020

Further information may be found by those who wish to study the facts, in papers which are printed in the 'Electrician,' (General Researches by M. Weiler, vol. xv. p. 436; Experiments on Arc Carbons, vol. xv. p. 162; and on Mercury, vol. xxv. p. 543), according to which the value of a millimetre column of mercury 100 centimetres high is B A units ·95352 instead of ·96185 as the table shows. Improvements in the working of copper have also resulted in producing metal having 104 per cent. the conductivity found by Mathiessen: but the changes made in the values of the standards themselves makes true comparison very difficult.

533. CORRECTION FOR TEMPERATURE.—It is convenient to adjust resistances at the ordinary temperature, 60 Fahr., and the values are given in the formulæ and tables at that point. But it is necessary for many purposes to know the resistance at temperatures different from that of observation, for temperature plays a very important part in the resistance of wires; in fact,

it is difficult to get the same resistance twice for a piece of copper wire, if it is touched, or if the slightest change takes place in the room. Tables of correction are given in many works, but they never point out that these tables only give a part of the correction required; they deal only with the temperature of the wire itself, but leave out of sight altogether the variation which takes place in the *measurement instrument itself*, though this is one-tenth of that of the copper wire as regards external temperature, and greater than that of the wire as regards any heat produced by the current itself. The latter cannot be dealt with except by careful valuation in each case; but for ordinary resistance measurement, with small and momentary currents, the external action alone need be considered. Instruments for measuring resistance ought to have marked upon them the temperature at which they are correct, then the correction for actual temperature, say in copper wire, would be, not that for copper merely, as given in the usual tables, but this less the simultaneous variation of the German silver wire of the instruments. Thus for each degree Fahrenheit near about 60°—

Copper varies as 1 to	1·00215	log	0·0009327
German silver varies as	1·00024	„	0·0003126
Combined correction at 60° ..	1·00191	„	0·0008287

The variation occurs not equally for each degree, but by a curve represented according to the experiments of the British Association Committee on Electrical Standards, by the formula for the resistance R at temperature t (Centigrade) from the resistance r at zero, $R = r\,(1 + a\,t \pm b\,t^2)$.

	a	b
Pure metals	0·003824	+ 0·00000126
Mercury	0·0007485	− 0·000000398
German silver	0·0004433	+ 0·000000152
Platinum silver	0·00031	

But for all ordinary purposes the correction above given will suffice, multiplying the decimal portion or the logarithm by the number of degrees (not by the logarithm of the degrees), and multiplying the resistance observed, for higher temperature, and dividing for lower temperature; adding or subtracting, as required, the logarithmic correction to the logarithm of the observed resistance.

Thus to correct from 60° to 32°, or the freezing point (zero Cent.) is 28° ·00215 × 28 = 1·0602 for copper. The correct figure, 1·0605, differs very slightly from this, and the mode of correction is shown, § 539.

It is probable that these figures apply only to moderate heats, and Müller gives the following resistances for high temperatures of certain wires experimented on.

Iron.		Copper.		Platinum.	
0° Centigrade	640	0° Centigrade	814	0° Centigrade	1870
21° „ ..	691	21° „ ..	864	21° „ ..	1986
285° „ ..	1660	Slightly incandescent ..	2100	Slightly incandescent ..	4300
Dark red ..	3200	Carmine red ..	2450	Red hot	4700
Bright red ..	3650	Brick red ..	3300	Orange	5400
White hot ..	4880	Bright red ..	4700	Light yellow ..	6000

On the other hand, carbon, as in the incandescent lamp, has a resistance, when cold, just about double of that when at full light-giving temperature.

Specific heat, the quantity which raises unit weight of any substance 1 degree in temperature, *increases* as the temperature approaches the point of a change of physical state, such as fusion. But Siemens, in his experiments on electric pyrometers, found the increase of resistance by heat reduced as the temperature rises, and that the resistance of a metal may be expressed as

$$R = \alpha \sqrt{T} + \beta T + \gamma$$

R being the resistance, T the absolute temperature (reckoned from absolute zero, $-273·7°$ Cent. or $-470·66°$ Fahr.), and $\alpha\, \beta\, \gamma$ are coefficients related to the particular metals.

534. Dimensions of Wires.—For electrical purposes, in addition to the ordinary commercial considerations of weight, length, and strength, we must include electric resistance; so that if we fix upon a definite unit which includes weight, length, and resistance, all considerations are resolved into mere multiples of that unit, as shown § 488.

Although we may buy and speak of wires by their diameters, this principle means that we should think, not of their diameters, but of their sectional area, which varies in the ratio of the square of the diameter. We must, in fact, regard the wires, not as single cylinders, but as though they were built up of a series of parallel unit cylinders of definite properties. Of course, the metric measures would furnish the best system, but as this is practically out of the question, the best plan available is to take for the unit of measure the one-thousandth of an inch, already frequently so used, and called a "mil." Since wires are round, and the areas of circles increase as the squares of the diameters, we should regard the "mil" as a circular wire. Then, by squaring the diameter in "mils" of any wire, we obtain direct its area in circular mils—that is to say, the number of unit wires to which it is equivalent. To make the unit complete, its length must be defined, and the foot is the most convenient measure. But as in electricity we require to include in our unit electric resistance as well as the weight, &c., it is still more convenient and generally useful to make weight, rather than diameter, the basis of the unit, and the most generally useful unit would appear to be a wire, 1 foot long, weighing 1 grain. By ascertaining the relation of this, for each metal, to the general circular *mil* foot, every necessary calculation can be readily effected. This relation is given, as nearly as present knowledge allows, in Cols. VI. and VII. of Table IX., p. 273.

535. WIRE GAUGES.—Wire is usually bought by Birmingham Wire Gauge. Here is, however, a name without an object belonging to it; for no one can tell what the Birmingham Wire Gauge is, and different dealers will differ two or three sizes; while, in the finer wires, it is a mere chance what will be obtained for any gauge asked for. But there is now a real legalised set of figures, known as the Standard Wire Gauge, by which traders would be bound; though, as in the process of wire drawing the sizes vary somewhat, it is by far the best plan to obtain wire, not by gauges, but by specified diameters, or weights per length.

STANDARD WIRE GAUGE.

No.	Inch.	No.	Inch.	No.	Inch.	No.	Inch.	No.	Inch.	No.	Inch.
7/0	·500	1	·300	11	·116	21	·032	31	·0116	41	·0044
6/0	·464	2	·276	12	·104	22	·028	32	·0108	42	·0040
5/0	·432	3	·252	13	·092	23	·024	33	·0100	43	·0036
4/0	·400	4	·232	14	·080	24	·022	34	·0092	44	·0032
3/0	·372	5	·212	15	·072	25	·020	35	·0084	45	·0028
2/0	·348	6	·192	16	·064	26	·018	36	·0076	46	·0024
0	·324	7	·176	17	·056	27	·0164	37	·0068	47	·0020
		8	·160	18	·048	28	·0148	38	·0060	48	·0016
		9	·144	19	·040	29	·0136	39	·0052	49	·0012
		10	·128	20	·036	30	·0124	40	·0048	50	·0010

536. *Logarithms.*—In applying the principles of § 534, and in illustrating the formulæ based upon them, I employ logarithms.

Some readers may think this abstruse, but it is the simplest of all modes of calculation, most accurate and rapid, and least fatiguing to the brain. Their use cannot be too strongly recommended to those who have to make many calculations, and have not practised the use of the slide rule, which is in fact a logarithmic machine. The examples and formulæ, having their decimal values given also, can be worked out in the ordinary manner by those who prefer to do so.

537. A Wire is simply *a cylinder occupying a certain measurement of space.* The weight of the cylinder will depend upon the specific gravity of the material which fills the space.

A *cubic inch of water* weighs 252·456 gr.,* and this multiplied by 12 and by ·7854 gives us the weight of a circular inch-foot of water; and that multiplied by the specific gravity of any metal gives the weight of a circular inch-foot of that metal, and thus the datum for all required calculations. I will work this out in logarithms, taking, as a basis, copper specific gravity 8·9, this being the average specific gravity of good copper wire:—

Cubic inch of water 252·456 ..	2·4021857
12 in. per foot	1·0791812
·7854, ratio of circle to square ..	$\bar{1}$·8950909
Circular inch-foot of water	3·3764578 = 2379·3
Specific gravity of copper 8·9 ..	0·9493900
Circular inch-foot of copper ..	4·3258478 = 21176·1

538. This divided by 1000 × 1000 = 1,000,000, gives the weight in grains of a wire of a circular *mil* one foot long. In this way are obtained the figures in Column II. of Table X. of the various constants required in calculations as to wires.

By dividing 1,000,000, the circular *mils* in an inch, by the weight of the circular inch-foot, we obtain the sectional area in *mils* (or number of *mils* it occupies) of a wire weighing one grain per foot. This gives Column III. of the Table of Constants.

1,000,000 = 10^6	6·0000000
Inch-foot of copper, 21176·1 ..	4·3258478
Mils per grain-foot, G.	2)1·6741522 = 47·22
sq. root	
Diameter of grain-foot	0·8370761 = 6·872

---

* A recent determination makes it 252·286, but it is not necessary to alter all the figures for that small difference.

539. Assuming as correct the resistance of one foot-grain wire given in Table IX., we obtain all that is necessary to complete the data, viz. the resistance of the unit foot-grain wire which I have calculated at 60° and inserted in Column IV. of Table X.

Resistance of soft copper,
One foot-grain at 32°, ·2064 .. .. $\bar{1}$·3147097
Correction for 28°, 1·0605 .. .. 0·0255107
Unit resistance at 60°, U. .. .. $\bar{1}$·3402204 = ·21889

540. CONSTANTS OF UNIT WIRES.—Table X. gives the principal constants required for calculations. Those for German silver and brass are for average values, and those of Column IV. for the grain-foot resistance U ought to be determined for any particular sample if exactness is required. In the case of German silver it may vary 50 per cent., and in that of copper, in proportion to its conductivity.

TABLE X.—CONSTANTS OF UNIT WIRES.

	I. Specific gravity.	II. M Grains per *mil*-foot.	III. G Area in *mils* per grain-foot.		IV. U Resistance at 60° Fahr. of foot grain.	
			Mils.	Logarithm.	Ohms.	Log.
Water	1·	·0023793	420·29	2·6235422		
Copper	8·9	·0211761	47·22	1·6741522	·2189	$\bar{1}$·3402204
Iron	7·8	·0185590	53·88	1·7314476	1·1634	0·0657173
German Silver	8·7	·0207003	48·31	1·6840229	2·6699	0·4264939
Brass	8·4	·0199865	50·03	1·6992629	·9938	$\bar{1}$·9972763
Platinum ..	21·4	·051006	19·61	1·2923782	2·8879	0·4760559
Carbon	1·6	·003807	262·68	2·4194222	95·592	1·9802392

541. FORMULÆ FOR WIRES.—As the following formulæ differ in several points from those generally given to attain the same results, it may be explained that this is owing to the definite system of which these form a part. Most other formulæ are single ones, devised each for its own purpose, and often based upon mere actual measures of particular wires, which often vary in quality. Those given here may have no actual superiority over these others, except as forming part of a definite system based upon mathematical truths, and linked especially to the conception of wires, not as each separate entities, but as consisting of collections of unit wires of definite property, thus giving to d^2 an extended meaning, from the mere square of the diameter of single wires to the number of units in all wires.

542. SYMBOLS USED IN THE FORMULÆ.—Let the following letter represent the requisite particulars.

W = weight in grains. $W \div 7000$ = weight in pounds.
w = ditto per foot = $M \times d^2$ or $d^2 \div G$.
M = ditto per mill-foot = $m \times s$ or $1 \div G$ or $U \div u$.
m = ditto ditto of water = ·0023793 Log. $^{-}3{\cdot}3764578$.
d = diameter in mills (inch ·001) = square root of d^2.
d^2 = square of diameter = area in circular mills = $w \times G$.
G = area in mils of the grain-foot = $1 \div M$ or $u \div U$.
g = ditto ditto of water = 420·29. Log. 2·6235422.
l = length in feet.
s = specific gravity. = $M \div m$ or $U \div (u \times m)$.
R = resistance in ohms at 60° Fahr. $U \times l \div W$.
r = ditto per foot = $R \div l$.
U = ditto ditto of the grain-foot = $r \times w$
u = ditto ditto of the mill-foot = $U \times G$ or see R.
R = specific resistance of cubic centimetre.
ohm = $u \times$ 0000016624. Log $^{-}7{\cdot}2207291$
ditto for microhms, index $^{-}1$; for C G S units 2.
$\mathit{R} \times$ reciprocal of these constants gives u.
$s \times m$ gives all the data for weight, &c., so that from these two data all requisite information can be calculated.

543. DIAMETER.—To ascertain the *size*, or *gauge*, or the *di* *meter of any wire*, d, weigh and measure carefully any convenier piece, and reduce to grains per foot. Multiply this by th constant G in Column III. (47·22 for copper). This gives th sectional *area* in circular *mils*, d^2, and the square root of this the diameter in *mils*, d.

$$d = \sqrt{w\,G}.$$

Ex. 4 ft. weigh 3·15 grs.	0·4983106
Divided by 4	0·6020600
w, grains per foot	$^{-}1{\cdot}8962506 = 0{\cdot}788$
G, constant for copper, 47·22 ..	1·6741522
d^2, sectional area	$2)1{\cdot}5704028 = 37{\cdot}10$
d, diameter in *mils*	$0{\cdot}7852014 = 6{\cdot}1$

For other metals proper constants should be used.

Resistance of a length being known × by conductivity and ÷ b length in feet to reduce to resistance per foot as pure coppe = r; then

$G \times U \div r = d^2$. $G \times U$ for copper = 10·3365 Log 1·014372
or $U \div r = w \times G = d^2$.

544. WEIGHT OR LENGTH.—*The diameter being known, to ascertain the* WEIGHT *of any length, or the* LENGTH *of any weight*, multiply the square of the diameter by Column II. of the Table, the grains per *mil*-foot. This gives the weight in grains per foot, from which all required weights and lengths are ascertainable by common arithmetic.

$$w = d^2 \mathrm{M}.$$

Or, dividing the square of the diameter by the area of the grain-foot, G, Column III., will also give the grains per foot.

$$w = \frac{d^2}{\mathrm{G}}.$$

545. *For copper wire*, the *square of the diameter*, with following constants, will give the particular information in each case.

		Log.
Feet per pound, divide by d^2 ..	330560	5·5192502
Yards per pound, ditto ..	110187	5·0421289
Grains per foot, multiply by d^2	0·0211761	$\bar{2}$·3258478
Lbs. per 1000 feet, ditto	0·0030252	$\bar{3}$·4807498
Lbs. per mile, ditto	0·015973	$\bar{2}$·2033837
Lbs. per nautical mile, ditto	0·018414	$\bar{2}$·2651531

The same constants, used in the opposite manner, will give the *area*, and hence the *diameter of a wire*, of which any of these particulars are known.

The following constants also furnish useful data as to copper wire; they are, in fact, the resistances of a wire of one-thousandth inch diameter, of the length named, at 60°, and are to be divided by the sectional area in *mils*, d^2.

		Log.
Ohms per foot at 60°	10·3365	1·0143726
Ohms per yard	31·0095	1·4914939
Ohms per mile	54,577	4·7370065
Ohms per nautical mile at 60°	62,918	4·7987759
Ohms per lb. divide by d^4 ..	3,416,825	6·5336228
Feet per ohm, multiply by d^2	0·0967447	$\bar{2}$·9856274

546. RESISTANCE.—*To ascertain the* RESISTANCE *of any wire at 60°*, divide the unit resistance U, Column IV., by the weight in grains per foot. This gives the resistance per foot, which multiply by length required.

$$\mathrm{R} = \mathrm{U} \times \frac{l}{w}.$$

Or, multiply U by the length in feet, and divide the product by the area multiplied by M, the grains per *mil*-foot.

$$R = \frac{U l}{d^2 M} \quad \text{or} \quad \frac{U}{M} \times \frac{l}{d^2}.$$

This last formula gives another constant, the resistance of the *mil*-foot at 60°, which might, if preferred, serve as the principal unit instead of the grain-foot.

547. CONDUCTIVITY.—Measure the resistance of any convenient length, correcting for temperature to 60°. Divide by the length in feet, and multiply by the weight in grains per foot. This gives the resistance per grain-foot, or specific resistance, by which divide the unit 0·21889. The quotient is the conductivity.

$$C = U \div \frac{R w}{l}.$$

The actual measurement of wire for its resistance, in order to ascertain its conductivity, may be effected on three distinct systems.

(1) The measurement of any length and reducing the length and resistance to the unit foot-grain or mil.

(2) By Clark's system. A standard wire of copper is mounted; its length or size is of no consequence, but its resistance is made 0·1516 ohm at 60°, being equivalent to a pure wire 100 in. long weighing 100 grains; the conductivity of any other wire is measured direct by balancing the necessary length against this, and will be as the square of its length in inches divided by its weight in grains. This has the advantage of requiring no correction for temperature, as both the wires vary alike, care of course being taken not to so pass current through as to act unequally on them.

(3) Measure and weigh any length of which the resistance is known, and multiply U by the length, and divide by weight per foot, which gives the equivalent resistance as pure copper which divide by the actual resistance.

The relative conductivity of any metal as compared with any other taken as standard can be calculated thus for equal weights or equal sections;

$$\frac{\text{U or } u \text{ of standard} \times 100}{\text{U or } u \text{ of substance}} \quad \text{thus} \quad \frac{\text{silver } u = 9{\cdot}151 \times 100}{\text{zinc } u = 34{\cdot}2} = 18{\cdot}45$$

Columns IV. and V. of Table IX. are obtained in this way.

548. COPPER.—This varies very greatly in its electric proper

ties, ranging in conductivity from 98 per cent. as low as 50. It is of great importance to attend to this, for in making an instrument, be it a galvanometer, an electro-magnet, or a coil, thin wire of good quality will allow the number of turns to be increased, or the instrument made of smaller size, with equal conductance, as compared with one made of poor wire.

Mathiessen gives the relative conductivity of various coppers as compared with hard-drawn silver:

Pure copper:		Temperature.
Oxide reduced by hydrogen	93·0	at 18·6 C.
Electrotype, not melted	93·46	„ 20·2 „
„ fused in hydrogen ..	92·76	„ 19·3 „

The conducting power increased about 2 per cent. by annealing the wires.

Impure, or commercial coppers:		Temperature.
Containing red oxide, melted in air	73·32	at 19·5 C.
„ 0·95 of phosphorus ..	23·24	„ 22·1 „
„ 2·80 per cent. of arsenic	13·14	„ 19·1 „
„ 1·60 per cent. of zinc ..	56·98	„ 10·3 „

Taking the pure electrotype copper as standard, or 100—

Spanish (Rio Tinto), containing arsenic, iron, lead, &c., was	14·24
Russian, with traces of same	59·34
Tough cake	71·03
Australian, Burra Burra	88·86
American, Lake Superior	92·57

These figures show that excellent commercial wire may be very bad for electrical purposes.

549. Table of Copper Wire.—This is calculated on the formulæ, §§ 543–6, for the most useful sizes of copper wire, but its readings may be translated into the values of other metals by the following constants:—

			Log.
1. Weights. Multiply by	Iron	·87641	−1·9427046
	German Silver ..	·977538	−1·9901293
	Brass	·94382	−1·9748893
2. Lengths. Multiply by	Iron	1·14003	0·0572954
	German Silver ..	1·02298	0·0098707
	Brass	1·05952	0·0251107
3. Resistance. Multiply by	Iron	5·3149	0·7254969
	German Silver ..	12·2009	1·0863826
	Brass	4·54	0·6570559

4. LENGTH OF RESISTANCE (Col. IX.) divide by the constants in 3, which are the conductivities, copper being 1. In like manner the conductivity of any commercial copper or other metal will give the correction to employ.

The most useful data have been chosen; thus 1000 feet is taken because the change of the decimal point converts the value into that of 1, 10, or 100, while multiplying by 5·28 converts it into a mile. The last column will be useful in selecting wires for any purpose, especially as multiplying by 12 gives the value in average German silver. The figures in the *foot-grain* and *mil* lines are the constants for use in the formulæ. The diameters are shown in millimetres for comparison when required; while the millimetre and metre-gramme lines furnish constants for calculations in the metric measures, in the same manner as is described for the foot-grain system.

550. RESISTANCE OF LIQUIDS.—For equal dimensions this is vastly greater than that of metals, but it is subject to the same laws; it varies inversely as the sectional area, and directly as the length. Therefore, by doubling the area, or what is frequently the same thing, doubling the size of the plates, we halve the resistance, or may double the distance apart without increasing the resistance. This holds exactly true only when the plate fills a cell of square section, as to which see § 553. The law also holds true only as to the real liquid resistance, the molecular motion in the liquids themselves. There are really three elements of resistance in most liquids:—

(1) The true liquid resistance just spoken of, and to which alone this section refers.

(2) The resistance at contact of the plate and liquid which varies the active area, as when a gas is given off and covers part of the surface: this may be regarded as analogous to dirty surfaces or bad soldering with wires, &c.

(3) An absorption of energy when an electrolyte is decomposed which has been given the confusing name of "polarization" of plates, as to which see § 292.

The resistance of a porous cell is really due to the reduction of the area of the liquid: hence, if this be measured in ohms, it will be different if the liquid is a good or bad conductor, as the real thing measured is the conducting capacity of the liquid absorbed in the pores.

Heat has the opposite effect in liquids to that upon metals: for heating *diminishes* the resistance. In some cases the resistance at 32° is three or four times as great as at 212°, and in the case of soda lye, nearly 100 times as great.

TABLE XI.—PROPERTIES OF COPPER WIRE. SP. GR. 8·9.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
B. W. Gauge.	Diameter.		Area in circular Mils = unit wires. (d_2)	Weight.		Length.	Resistance as Pure Copper at 60° Fahr.		
Col. II. of Table.	In Mils. =·001 in. (d)	Milli-metres.		Grains per foot. (w)	Pounds per 1000 feet.	Feet per pound.	Ohms per 1000 feet.	Feet per Ohm.	Ohms per pound.
centimetre	393·7	10·	155003·	3282·4	468·92	2·13	0·0667	14996·	·00014
¼	250·	6·37	62500·	1323·5	189·07	5·29	0·1654	6046·5	·00088
6	200·	5·08	40000·	847·1	121·01	8·26	0·2584	3869·8	·00214
inch.	180·	4·57	32400·	686·1	98·02	10·20	0·3190	3134·6	·00326
8	170·	4·31	28900·	612·0	89·46	11·18	0·3495	2861·0	·00391
9	155·	3·94	24025·	508·8	72·68	13·76	0·4302	2324·3	·00592
10	140·	3·55	19600·	415·0	59·29	16·87	0·5274	1896·2	·00889
⅛	125·	3·17	15625·	330·9	47·27	21·16	0·6615	1511·6	·01400
11	120·	3·05	14400·	304·9	53·56	23·28	0·7178	1393·1	·01648
12	110·	2·79	12100·	256·2	36·69	27·32	0·8543	1170·6	·02334
	100·	2·54	10000·	211·8	30·91	33·06	1·0336	967·5	·03417
13	95·	2·41	9025·	191·6	27·30	36·63	1·1453	873·1	·04195
14	85·	2·15	7225·	153·0	21·12	46·28	1·4472	691·0	·06698
15	75·	1·92	5625·	119·1	17·02	58·77	1·8376	544·2	·10799
	70·	1·778	4900·	103·76	14·82	67·46	2·1095	475·1	14241
16	65·	1·651	4225·	89·47	12·78	78·24	2·4465	408·8	19141
1/16	62·5	1·587	3906·	82·72	11·82	84·62	2·6462	386·7	22392
	60·	1·521	3600·	76·23	10·89	91·82	2·8712	348·3	26370
17	57·	1·440	3249·	68·80	9·83	101·75	3·1814	314·3	·32369
	55·	1·397	3025·	64·01	9·15	109·28	3·4170	292·0	·37340
18	50·	1·274	2500·	52·94	7·563	132·22	4·1346	241·9	·54669
19	45·	1·143	2025·	42·88	6·126	163·25	5·0927	196·0	·83324
	43·	1·092	1849·	39·16	5·593	178·78	5·590	178·9	·99910
	42·	1·066	1764·	37·36	5·236	187·39	5·8597	170·7	1·0981
20	40·	1·016	1600·	33·88	4·840	206·60	6·4603	154·8	1·3347

millimetre	39·37	1	1550·	32·823	4·689	213·26	6·669	151·0	1·429
21	35·	·889	1225·	25·941	3·705	269·84	8·438	118·5	2·278
22	32·	·813	1024·	21·684	3·101	322·81	10·094	99·1	3·259
	31·62	·803	1000·	21·176	3·025	330·56	10·336	96·7	3·417
	30·	·762	900·	19·059	2·729	367·29	11·485	87·1	4·218
23	28·	·711	784·	16·602	2·371	421·63	13·184	75·9	5·559
24	25·	·635	625·	13·235	1·891	528·90	16·539	60·5	8·747
25	23·	·584	529·	11·202	1·604	624·88	19·540	51·2	12·210
26	19·	·483	361·	7·648	1·092	915·78	28·633	34·9	26·219
27	18·	·457	324·	6·845	·991	1020·3	31·902	31·4	32·549
28	16·	·406	256·	5·421	·774	1291·3	40·377	24·8	52·137
29	15·	·381	225·	4·765	·681	1469·1	45·940	21·8	67·493
met.-gram.	14·9	·379	222·13	4·704	·672	1488·1	46·534	21·5	69·250
30	14·	·355	196·	4·151	·593	1690·4	52·727	19·0	88·943
31	12·	·305	144·	3·049	·435	2295·6	71·780	13·9	164·78
32	10·	·254	100·	2·118	·303	3305·6	103·36	9·7	341·68
34	9·6	·244	92·16	1·952	·279	3586·8	112·16	8·9	402·29
	9·	·228	81·	1·715	·246	4081·0	127·90	7·8	520·78
35	8·7	·221	75·69	1·603	·229	4367·3	136·56	7·3	596·41
	8·	·203	64·	1·355	·194	5165·0	161·51	6·2	834·19
36	7·9	·200	62·41	1·322	·189	5296·6	165·62	6·0	877·23
Foot-grain	**6·872**	**1·75**	**47·22**	**1·**	**·14286**	**7000·**	**218·89**	**4·5684**	**1532·2**
37	6·7	·170	44·89	·951	·136	7363·7	230·26	4·3	1695·6
38	5·8	·147	33·64	·712	·102	9826·4	307·27	3·3	3019·3
	5·5	·139	30·25	·641	·092	10902·	341·70	2·9	3734·0
	5·	·127	25·	·529	·0756	13222·	413·46	2·42	5466·9
39	4·2	·106	17·64	·374	·0534	18739·	585·97	1·71	10981·
	4·	·106	16·	·339	·0484	20660·	646·03	1·55	13347·
40	3·9	·099	15·21	·322	·0460	21732·	679·58	1·47	14769·
41	3·3	·084	10·89	·231	·0329	30354·	949·17	1·05	28812·
	2·	·0508	4·	·085	·0121	82640·	2590·1	0·39	213562·
Mil.	**1·**	**·0254**	**1·**	**·0211761**	**·0030252**	**330560·**	**10336·5**	**·0967447**	**3416825·**

551. Except metals when fused, or liquid like mercury, liquids appear not to conduct electricity otherwise than by electrolytic decomposition. Thus oils, alcohol, &c., are very perfect insulators, and even water, when absolutely pure, does not conduct, but when containing gases or saline bodies it breaks up and conducts: then the conductance depends upon the specific property of the substance, and the concentration of the solution.

552. I have collected the most important information available in the following Table, from which it appears that in some cases saturated solutions are the best conductors; in others there is a particular degree of saturation at which resistance is least, conductivity diminishing both above and below it. These latter are deliquescent or extremely soluble salts.

RESISTANCE OF LIQUIDS AND INSULATORS.

I.		II.	III.	IV.	V.
	Substance.	Resistances compared to Copper.	Specific Resistance.	Temp. Centigrade.	Variation per cent. per Deg. C.
1	Copper, hard	1·	1642·	0°	·377+
2	Mercury	58·20	96146·	,,	·072+
3	Copper sulphate, saturated	16,855,520·	CG S units per cub. cent.	9	
4	,, ,, diluted to half	26,327,637·	§ 446	,,	
5	,, ,, 1 lb. per gallon	18,450,000·			
6	,, ,, $CuSO_4 + 45H_2O$	.. ..	1·95×10^{10}	22	
7	Zinc sulphate, saturated	15,861,267·	..	13	
8	,, ,, diluted to half	12,835,836·	..	,,	
9	,, ,, $ZnSO_4 + 23H_2O$	.. ..	1·87×10^{10}	23	
10	Sodium chloride, saturated	2,903,538·	..	13	
11	,, ,, diluted to half	3,965,421·	..	,,	
12	H_2SO_4 ·2 per cent. in water	.. ..	4·47×10^{10}	..	·47 −
13	,, 8·3 ,, ,,	.. ..	3·32×10^{9}	..	·653 ,,
14	,, 20 ,, ,,	.. ..	1·44 ,,	..	·799 ,,
15	,, 35 ,, ,,	.. ..	1·26 ,,	..	1·259 ,,
16	1 vol. to 11 of ,,	1,032,000·	..	20	
17	Nitric acid, sp. gr. 1·264	1,606,000·			
18	,, ,, 1·31	976,000·	..	13	
19	Distilled water	6,754,208,000·	7·18×10^{10}	22	·47 ,,
20	Rain ,,	40,652,723·			
21	Selenium, vitreous	.. ..	6·×10^{13}	100	
22	Glass	variable	2·27×10^{16}	200	
23	Mica	.. ..	8·4×10^{22}	20	
24	Gutta-percha	Latr. Clark	4·5×10^{22}	24	
25	,,	Everett	3·51×10^{23}	,,	see § 94 (*b*)
26	,,	,,	7·×10^{24}	0	
27	Shellac	.. ..	9·×10^{24}	28	
28	Hooper's material	.. ..	1·5×10^{25}	24	

553. STRUCTURE OF LIQUIDS.—It is generally assumed that the fluid state is structureless, but the peculiarities of liquid conductance indicate the presence of something like structure, and

may throw light upon the nature of solution and upon the question whether crystalline bodies dissolve as such, with their water forming part of the dissolved molecules, or whether only the salt itself is dissolved. Many chemical facts tend to show that salts which crystallize in two or more forms with different amounts of water, have different solubilities in the different forms. A German chemist has quite recently asserted that some liquids, organic substances, show definite axes of elasticity, like crystals, when a drop is examined under a microscope by polarized light. At all events it is well known that many liquids do this when placed under electric or magnetic stresses, so that the lines of force can be traced in them: even in the ordinary condition, the rotation which is set up in the polarized rays of light implies that the solution is not really homogeneous but possesses some sort of structure, just as apparently transparent crystals do.

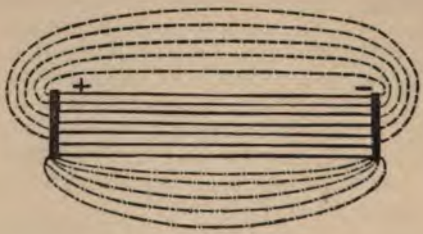
554. CONDUCTION THROUGH LIQUIDS.—It might be supposed that electricity takes only the shortest and straightest path, as it is often asserted that lightning does, and that in a liquid with two plates in it, the current would be confined to the stratum of liquid lying between the plates. This is not the case. Electricity divides itself through every path open to it in the ratio of the resistances of each path. Therefore if small plates are immersed in a large vessel, every particle of liquid in the vessel will form itself into a path for current. This may be tested by means of two wires fixed into a frame and connected to a galvanometer. On dipping these into a liquid through which current is passing they will form part of the circuit, replacing the liquid lying between them, although they have no metallic connection to the plates or battery. In this way the direction and density of the distribution of current may be mapped out, just as it may in a sheet of tin foil by means of a pair of points used in a similar manner.

Fig. 63 shows the facts: even the backs of the plates take part in the action, and it is greatest upon the edges, from the same causes which render points and edges active in static electricity, § 96. Hence, the backs of battery plates are to some extent active. Mount a pair of plates with one side varnished, as a battery or in a coppering cell with a galvanometer, and note the effect when the varnished or the bare sides are opposed.

555. EARTH CIRCUIT.—These facts explain why the resistance to a telegraphic return current by earth plates is so small as to count for nothing as compared with that of the wire. The return current passes through the liquids of the earth and sea just as in the case of a common decomposition cell, and its plates

are subject to the same effects of polarization, but the lines of current are not limited; they spread out in all directions, as in Fig. 63*, and the result is that the only actual resistance is of the order 2 and 3, § 550. There is another theory, favoured chiefly by mathematicians, that the earth may be regarded as an infinite reservoir, § 35, or else as an infinite pair of condensing plates in which the potentials set up in the wire are lowered to zero.

FIG. 63*.



But if we enclose a liquid, or moist earth in a tube, we find that tube is a conductor, and it acts in all respects as a wire does; we may lengthen it or add tube to tube, still the same, still the resistance as it grows obeys the definite laws: why then set up a new idea when we deal with the earth? This is, we know, a mass of electrolytes, and we know also that the plates act exactly as two plates in a solution do. The analogy has another view: if we use a copper earth plate in London and a zinc earth plate at a distance and in such a direction as eliminates the disturbing action of the natural currents of the earth, these plates act precisely as though they were in a cell, they produce a current traversing the wire, and if we soak the earth around the copper plate with a copper salt, we get all the effects of a Daniell cell: is it not obvious then that the intermediate earth is acting precisely as does the liquid in an ordinary cell and completing the circuit of the current?

556. MEASUREMENT OF LIQUID RESISTANCES.—This is difficult because of the so-called "polarization" effects at the electrodes, and the skin resistance, § 550. Most experimenters employ Poggendorf's method of alternating current, but it seems very doubtful whether this really measures the conductance of the column of liquid, or the successive charges set up on the plates and the liquid, acting as condenser. A very simple instrument

which I devised many years ago gets over all difficulties and reduces the measurement to the same conditions as those of wires.

It is a Wheatstone bridge (see p. 228), in which tubes of different lengths replace the wires in A and C. This is done by means of a U tube, one of the arms of which is provided with a second tube which divides the liquid into a long column into the other leg and a short one into this extra opening. This tube is suspended in a frame fitted with binding screws, and attached to the cover of a vessel containing water, by means of which the temperature can be varied at pleasure.

From these screws electrodes are connected, which dip into the enlarged necks of the U tube: these are varied to suit the nature of the liquid, and the whole principle of the action is that the *current*, and therefore the disturbing actions, *shall be equal in the two branches.* One of the short arms is connected to the battery, representing – of the bridge, the other represents the opening A and is completed by a resistance instrument, by which the circuit is equalized with that of the farther arm of the U tube, so that the *difference in length of the two columns* of liquid is exactly equal in resistance to this extra resistance inserted. Under these conditions, provided that the plates are connected together to get rid of any charges, all disturbances may be ignored, because they are equalized in both arms: then the resistance will vary with the strength of the current. Of course either a good differential galvanometer may be used to replace B and D of the bridge, or suitable resistances can be employed, but no multiplying ratios are permissible.

The data of the tubes may be ascertained by first measuring some liquid taken as standard. An open oblong cell may be used in place of tubes, provided that the plates completely fill the cross section; in this case the two sides of the middle plate distribute the two currents.

557. Heating of Wires.—The law of the heat developed by the current is $C^2 \times R$, or $E \times C$, the unit being the joule, § 426, expressed in any desired form. This relates to the "quantity of heat" generated per second. The actual rise of temperature produced by this quantity of heat in different substances is described, § 387.

It is necessary now to consider what becomes of this heat, and the ultimate effect, which for practical reasons may be most conveniently studied as relating to *copper* conductors, this becoming nowadays a most important subject.

This has received much attention from those engaged in electric lighting, but the information accessible is still imperfect, and a valuable trading possession of those concerned: therefore whatever may be said now is subject to further advances in knowledge.

558. *Dissipation of Heat.* — Heat always passes away from a body of higher temperature to its surroundings of lower temperature; it does so at a *rate* dependent on the difference of temperatures, and upon the specific properties of surrounding bodies. There are three modes of transmission, *Conduction, Convection*, and *Radiation*; these must be studied in works treating of heat, but a slight sketch of their relations to electric conductors is necessary, because each process has its own part to play.

Conduction is transmission from particle to particle of a substance, always from the hot part to the cold, therefore, in conductors, from the interior towards the surface.

Convection is the heating of gas or liquids in contact with the surface, which, becoming lighter, rise and give place to cooler molecules, carrying the heat away with them.

Radiation is the constant escape of heat from the surface, across space, or through air, &c., which is not itself heated, but transfers the energy of heat to surrounding surfaces which are capable of receiving it and reproducing it as heat.

559. *Conduction of Heat* is effected from molecule to molecule much as electricity is, and the conductivities of metals are in closely the same order for heat as for electricity, though the rate of transmission is much smaller. The time of cooling of similar bodies is as the square of their linear dimensions, therefore, in the case of electric conductors, the rate of cooling of the interior portion will be as the squares of their radii (or diameters), which means *as their sectional areas*, subject, of course, to other considerations. It is evident, therefore, that several small conductors will be cooler than one equal to the sum of them.

Fig. 28, p. 78, may be regarded as the section of a conductor, showing successive shells of the substance transmitting the heat from one to the other.

Insulating materials conduct heat badly as well as electricity, therefore they tend to retain the heat in the wire: but on the other hand, their surfaces radiate heat more freely than smooth metal does, and the total effect is that covered wires cool better than bare ones, losing heat at 25 per cent. greater amount. Most insulators are also liable to injury by the heat, and therefore their nature limits the temperature, and it is obvious that their thickness should be as small as is consistent with effectual insulation.

Iron would evidently be greatly inferior to copper as a conductor for large currents, not merely on account of its lower conducting power necessitating an equivalent increased weight, but because this increased size would retain the heat in the conductor.

One effect of the difference of the heat at the inner and outer parts of the conductor is to make the different parts unequal in conductivity, tending, as it were, to thrust a larger part of the current to the outer portion of the conductor; this again tending to the production of greater heat in these parts, and thus to the restoration of equilibrium. The distribution of heat in the section of the conductor will certainly not be that of a body first heated and then allowed to cool, but one of nearly equal temperature throughout, accompanied with frequent small changes in the distribution of current throughout the mass.

560. CONVECTION OF HEAT.—When a conductor is surrounded by a liquid, the same action occurs as may be seen in water heated in a metal vessel, where a continuous stream of heated particles runs upwards: therefore in a large mass of water the heat of a conductor would be kept down nearly to that of the water, at its surface, and at its interior in proportion to the property of conduction and size. In air the same action occurs, and in other gases it appears to occur at a rate related to their specific gravity, hydrogen having the greatest cooling action.

If two pieces of platinum wire of equal dimensions and resistance are enclosed in tubes containing, 1, air, 2, hydrogen, the same current passing through them will raise 1 to red heat, while 2 remains dark. If the two tubes are placed in equal quantities of water and the current passed through both, the water surrounding 1 will be more heated than that around 2, though the R of each was the same at first; wire 1, becoming more highly heated, its resistance is the greatest, and therefore in it the same current develops greater heat.

Dissipation of Heat by Convection plays an important part in conductors exposed to the air, and care should be taken to facilitate the action by not placing them close to ceilings or where circulation of air is difficult. It is evident also that thin strips of metal placed vertically will be kept more cool than the same mass of metal in a solid rod.

561. RADIATION OF HEAT.—This action is always going on from all bodies, each emitting and each absorbing heat, with a tendency to bring all to the same temperature. The same conditions facillitate emission and absorption, and the chief of these conditions appear to be the nature of the surface. The

subject of radiant heat or energy is of great importance in the generation of light, but as regard conductors it is of interest only in so far that its laws show that the metal surface, if exposed, should not be polished, but is best blackened with lampblack and size, and that if enclosed, the outer surface should be of a nature to assist radiation. Fig. 23 will also convey an idea of radiation, + being the conductor surrounded by air.

562. SAFE CURRENT IN WIRES.—It is evident that these three actions have different bearings in different cases. With small wires exposed to the air, convection and radiation are of most consequence. With covered conductors radiation may be of importance; but with conductors insulated and placed underground, conduction, and that the conduction of the materials of the earth, will be the principal agency.

No definite laws of relation of current to size of conductor are possible: the conditions must be adapted to each order of circumstances. This is a highly technical subject, which taxes the knowledge of the most capable engineers, and therefore it cannot be fully considered in a work such as this, addressed to general readers and students: only the general principles can be set forth; but the reader who wishes to study the subject will find very full experiments recorded in a paper read by Mr. Kennelly to the Edison Convention in 1889, which will be found in vol. xxiv. of the 'Electrician,' pp. 143, 169, and 190.

The early Provisional Orders of the Board of Trade gave a limit of 2000 amperes per square inch of section, afterwards reduced to 1000, and now changed to the regulation mentioned § 565.

563. As 1 grain per foot means 47·22 mils (by § 545), 1000 amperes per square inch means 26·962 grains per foot per ampere, which figure or its Log 1·4307568 would serve as a basis for calculations as to size of conductors, multiplying it by any preferred value.

But it is more convenient, when treating of round wires (§ 538), to use 1000 amperes per circular inch as the datum; this makes all the requisite calculations and data decimal ones connected to the system and formulæ of wires already used in these pages. Then we have as unit a wire 31·625 mils in diameter (a small 22 B.W.G.), which is simply the "mil" unit of the previous formulæ and the following data multiplied by 1000.

The following are the values of current and dimension arrived at by different authorities, reduced to—

Ampères per sq. inch.	Circular mil.	Mils per ampère.
2000 =	·0015708	636·617
1750	·0013744	727·574
1200	·0009210	1085·75
1000	·0007854	1273·24
800	·0006288	1591·57
500	·0003927	2546·47
Siemens	·0014186	704·92
W. Smith	·0014313	732·12

This system, and the following data will facilitate calculations:—

	Mil-current .. .. ampère	·001	Log.	−2·0000000
A	Mils per ampère (*ampère foot*)	1000·	”	3·0000000
w	Weight, in grains per foot, per ampère..	21·275	”	1.3258478
	” lbs. per 1000 feet, ditto ..	3·025	”	0·4807498
J	Resistance per ampère foot at 60° Fahr. Heat in ditto, per second, Joules	·01034	”	−2·0143726
	Multiplied by square of ampères ..	× C^2	”	of C × by 2
	Correction for temperature per deg.	1·00215	”	0·0009327
H	Rise per second in degrees Fahr.	·03321	”	−2·508005

It is evident that these last values must be reckoned, not at the temperature of the surrounding air, but at the limit of temperature of the metal in full work.

564. *The size of the conductor must modify the mil-current:* that is to say § 564 shows that as the size of conductors is increased the specific capacity lowers. In the second edition of this work I suggested that the ratio of area to current (which shall maintain equal temperature in the conductor) will be described by a logarithmic curve in which the ampere area will be gradually increased: such a curve would probably be of the character of $d = \sqrt{C \times C k}$, in which k would be a value to be determined by experiment. In other words the mil-current would be gradually lowered, or the ampere area increased in some ratio of C.

Experience has proved this to be the case, and several such curves are now employed.

The question really is, *what rise in temperature can be permitted?* Of course the initial mil-current would be different according to whether bare wires were used, or insulation of different kinds; also the permissible rise will vary greatly under different conditions. Bare wires in inaccessible positions would allow a much higher temperature than insulated wires, or wires traversing spaces where injury can be done. On the other hand, insulated wires cool most rapidly, § 559.

565. The next question is how to balance generation and dissipation of heat; to secure a defined equal temperature in conductors carrying different currents. The dissipation of the heat is in fact, whatever the mode, a function of *surface*, and in rods, square or round, *surface* increases *as the diameter* only, while area, or current-carrying power, increases *as the square of the diameter:* therefore with equal mil-currents, the heat in the conductor increases as the square of the surface through which it is to be dissipated.

A rule given by the Committee of the Inst. of El. Engineers for fire risks, and adopted by the Board of Trade, is the "conductivity and sectional area of any conductor should be so proportioned to the work it has to do, that if double the current proposed be sent through it, the temperature of such conductor shall not exceed 150° Fahr."

The Inst. of Engineers of the Colony of Victoria have fixed upon the formula C $\sqrt{\frac{D}{R}}$ where R is the resistance of 600 feet of the conductor at 150° Fahr., and D its diameter in mils. This gives a current density greater than 1000 amperes per square inch for small conductors, and considerably less for large ones, the conditions shown (§ 564) to be proper.

566. Mr. Kennelly shows that a rise of 10° Cent. is a permissible limit, practically that adopted by the Board of Trade, § 565, and gives the formulæ of the curve arrived at by experiment as

If d be in inches $C = 500$ $d^{\frac{3}{2}}$ and $d =$ 0·0147 $C^{\frac{2}{3}}$
" " mils " 0·01755 " " 14·7 "
" " millimetres " 4·375 " " 0·374 "

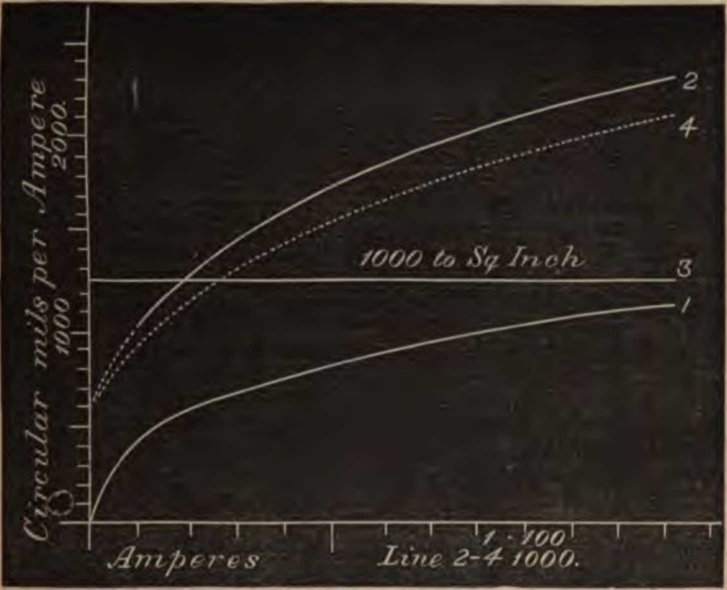
and when d is in inches and C in amperes $d = \sqrt[3]{\frac{C^2}{70}}$.

These formulæ are for insulated copper wire of 98 per cent. conductivity enclosed in wooden cases, as is now generally done.

Fig. 64 presents, in a simple manner, the relation of dimension and current, or what may be called *millage* and *amperage*. I have calculated the results into curves. The horizontal line of amperes shows up to 120 for curve 1, and up to 1200 for line 2, the scale of millage being the same for all in the vertical line. The diameter of the required wire can be obtained by multiplying together the amperes required and the millage shown by the curve: this gives the area d^2 in circular mils, and the square root of this is the diameter.

Line 3 shows how misleading the 1000 amperes per square inch is, and curve 4 is one calculated from the figures of Prof. Forbes, based on his formula $C^2 \propto d^3$ and certain theoretical data as to heat. It relates to bare wires and a temperature rise of 25° Cent. The general agreement of these curves shows that we have the truth pretty closely. The curves can easily be prolonged to higher currents; or they can be lowered to suit other conditions without much difficulty.

FIG. 64.



SAFE CURRENT IN COPPER WIRES.

567. COST OF CONDUCTION.—The heat generated in the conductor has another bearing; the greater the heat the greater the loss of energy in transmission; that is, § 426, as the square of the current forced through a given conductor, or greater than this by the diminished conductance due to the heat itself. This is therefore a question of *continuous working expenses.* On the other hand, if the capacity of the conductor be increased, so as to reduce this expenditure of energy, there arises the question of capital outlay, and interest.

The determination of the relative importance of these two depends upon the conditions of each particular case. If the conductor is to be regularly worked to its full capacity, the working expenses are most important. If the conductor is employed only a part of the time, the capital outlay is a serious consideration, and it would be better to endure a higher working cost. The cost per electric horse-power, § 427, at any given place, and the cost of the conductor at the same place, are variable elements upon which also the decision depends.

568. Sir W. Thomson says that cost is lowest when

$$\text{Cost of energy} = \text{Cost of conductor.}$$

That is to say, (1) the cost per horse-power of steam or other motor + the cost of transforming it into electric energy by the dynamo machine, is reduced to some unit of time, as per hour or year: this multiplied by the horse-power expended in the conductor gives the cost of energy. (2) The interest on cost of conductor, and the expense of repairs and depreciation taken for the year, or divided by the number of hours of working, gives the other side of the equation, and the two together are the cost of transmission of the current.

569. *Equal currents can transmit different quantities of energy.* A given conductor will carry different currents, and the expenditure of energy in the transmission will then increase as the *square of the current*, but will remain an *equal proportion of the energy transmitted*; this is the meaning of the statements quoted § 473. But there are conditions in which the same conductor will transmit greatly increased energy while expending no more within itself. This depends on the increase of E M F, and a proportional increase in the total resistance.

Let two points, generator and receiver, each of 1 ohm R, be connected by a conductor of 1 ohm. Now an E M F of 3 volts produces $C = 1$, and 1 joule energy will be expended in the conductor. Let the generator be so altered as to generate 2000 volts, and the receiver to utilize this E M F, raising the resistance of generator and receiver to 1999 ohms. We have still only a current $C = 1$, expending 1 joule energy per ohm, losing therefore still only 1 in the conductor, but while passing into the receiver, utilizing so much as corresponds to its proportion of the total resistance: the loss of energy in this case is in the generator, which necessarily has a higher resistance than in the first case.

The result is that, the higher the E M F employed the greater the economy of electrical work. But though this is theoretically true, the difficulties of insulation and the extra cost of the conducting system as a whole, makes the question of economy a very debateable one.

Some of the electric light companies run to 20,000 volts with alternating currents; but eminent engineers claim that low voltages are on the whole more economical.

570. Economical Size of Wires.—I have adopted the formulæ given by Mr. B. Rhodes in a paper read to the American National Light Association, 1889, altering the symbols to correspond with those used here.

Let

d = diameter of wire in mils.
L = length of line in miles.
p = price of bare copper per lb.
w = cost of power per H.P. per year.
C = current in amperes.

$\cdot 016\, d^2$ lbs. of wire per mile; $\cdot 016\, p\, d^2$ cost per mile of wire.
$\cdot 0016\, p\, d^2$ interest and depreciation at 10 per cent.
$\cdot 0016\, L p\, d^2$ = annual cost of wire. . . . . . . (1)

$$\frac{54577}{d} = \text{ohms per mile}; \; \frac{54577\, C_2}{d^2} = \text{watts per mile};$$

$$\frac{54577\, C^2}{746\, d^2} = \text{H.P. lost per mile}; \; \frac{54577\, C^2 w}{746\, d^2} \text{ cost of H.P. lost};$$

$$\frac{54577\, L\, p\, C^2}{746\, d^2} = \text{annual cost of power lost in the whole circuit} \qquad (2)$$

With increase of size (1) will increase and (2) diminish, and the best value of d will be such that their sum will be a minimum. Let u represent this; then

$$u = \cdot 0016\, L p\, d^2 + \frac{54577\, L\, w\, C^2}{746\, d^2},$$

which gives

$$\cdot 0032\, p\, d - \frac{109154\, C^2 w}{746\, d^3}.$$

Placing this equal to zero and reducing, we have

$$d^4 = \frac{45700\, C^2 w}{p}.$$

This shows that the size of wire depends on the price of copper, cost of power, and rate of current, and is independent of length of the circuit and the voltage. The cost of insulation also is not part of the calculation.

CHAPTER VIII.

ELECTROMOTIVE FORCE.

571. *Electromotive force* is the general name for whatever may be the agency which sets up electrical current. Some writers object to the use of the term, which is, however, too useful to be set aside. E M F corresponds to, and is always accompanied by, *potential* in static electricity, § 91; hence it is often called *electric pressure*. *Voltage* is also a convenient descriptive term which is commonly used. Some of the principles which underlie the term E M F are studied §§ 172–4 and 478–492, and in this chapter the main purpose is to trace them out by means of the chemical relations of electricity. It may be thought that, as batteries are of comparatively little practical importance now that the dynamo is our chief source, their chemical theory may be set aside. This would be a great mistake, because it is here, and here only, that we can trace the natural conditions of electricity apart altogether from mathematical assumptions and mere conventions, because the origin of the energy and force is *within the circuit* itself.

572. To Measure Electromotive Force.—This may be effected in absolute measure, but it is usually done in terms of some cell the E M F of which is known, such as the Daniell, which can be used while working, or the Clark, which requires opposition without current.

With a delicate galvanometer of which the current value of the deflections is known, such as a sine or tangent galvanometer, or any of those, now common, which give their reading in amperes, and a large resistance, the amount of which need not be known provided it is always the same, the E M F is proportional to the deflection value, and having once ascertained the angle given by a Daniell, and from it that due to 1 volt, the instrument can be marked, or a table made of the deflections, so as to read off direct in volts the E M F causing the deflection. If the resistance is made very large the internal resistance of the cell may often be neglected if not known. See § 577.

573. *Wheatstone's plan* is available either with large or small resistances: it depends on the production of two constant deflections, and I will use in the formulæ capital letters for the standard cell and small letters for the one to be measured, E, *e*,

being E M F in volts, R, r resistance in ohms, C, c current in amperes, and A, a the standard cell and that to be measured.

A is connected with such resistance as produces the first fixed deflection, say 20°, and a further resistance, R, is added to bring the deflection to a second fixed angle, say 10°.

a is now arranged to give 20°; the resistance required for this need not be measured, as it will vary with the internal resistances and has nothing to do with the calculation: further resistance, r, is now added to bring the needle to 10°, then

$$e = \mathrm{E}\,\frac{r}{\mathrm{R}} \text{ in volts.}$$

574. This may be simplified by once for all ascertaining the resistance value of 1 volt, as I will show by an experiment.

A large Daniell, with an external resistance of 2·41 ohms and a total resistance of 2·91, marks 20° on a galvanometer; an extra resistance of 3·11 brings it to 10. Of course it will require the same total resistance with any other Daniell, large or small, to reproduce these deflections; but the external resistances will be different in each case, for the first deflection; the second extra resistance will be always constant: it is, therefore, a figure representing 1·079 volt on this instrument between these angles, then 1·079 : 1 .·. 3·11 :: 2·882. This gives the resistance equivalent to 1 volt, and all future experimental resistances divided by this give the force of the cell under trial; for instance, a Smee cell in full work took 1·35 extra resistance to bring the needle from 20° to 10°. The formula works out thus:—

$$1{\cdot}079 \times \frac{1{\cdot}35}{3{\cdot}11} = {\cdot}468.$$

By using the constant obtained at the first experiment, the multiplying by 1·079 is for ever after unnecessary, for $\frac{1{\cdot}35}{2{\cdot}882} = {\cdot}468$. This is the simplest and best plan for obtaining actual working forces of batteries at any time, and therefore it is retained in this edition, while others formerly given are omitted, owing to the altered conditions, both of working and of available galvanometers.

575. *By Condensers.*—The E M F of cells may be compared by the several charges they can give to a condenser, but this process is one most useful in such technical work as testing cables, and those employed in such work will have access to those books which enter into this class of subjects more completely than is possible or necessary here.

576. The best of all modes of measuring the difference of potential between any two parts of a circuit or the E M F of a battery, whether working or not, is by means of a delicate electrometer such as the quadrant electrometer of Sir W. Thomson fitted with a replenisher and a gauge (which is itself a disc electrometer), to keep the charge of the movable part perfectly uniform and of known degree: a variation of this charge enables varying forces to be measured, because the deflection is determined by its intensity as well as by the charge derived from the force to be measured, which is given to the quadrants.

577. Voltmeters.—These are really galvanometers which fulfil the conditions of § 572, and every instrument-maker has his special construction. They are simply small current galvanometers of large resistance compared with the resistance of the circuit, to which they really act as *shunts:* as therefore this resistance is considered as of no account, the measurement of the potential difference is only approximate; any construction of galvanometer can be used, but as such measures are required in the neighbourhood of large currents and dynamo machines, the instruments ought not to be affected by them. The resistance may be produced by a separate coil or in the wire of the instrument itself: the latter is best, so as to have a large number of turns of wire, with needles whose control is such as to resist the influence. The greater their resistance is, the better, but for practical reasons, such as expense, it is related to the degree of voltage an instrument is to measure.

578. Apparatus for Experiments.—As some readers may wish to make experiments on chemical combinations, such as are here examined, I will describe the apparatus and process I have, after many trials, found most convenient, the object being to exchange one part for another rapidly, and without confusion or mixture of substances. It consists of:—

(1) A stand fitted with two binding screws for the wires to go to the galvanometer and resistance, which connections may thus remain undisturbed for any required time: the screws are connected to two mercury cups into which the wires from the elements dip, thus permitting these to be instantly exchanged.

(2) A U tube of glass or wood cemented, or a vessel with a partition descending nearly to the bottom; this contains dilute sulphuric acid or other liquid suitable to the other liquids to be employed at the two elements which it serves to connect.

(3) A number of small porous tubes (3 × 1 inch are suitable) capable of being supported in the U tube at the proper height.

(4) The various metallic plates are each fitted with a wire of such length as to dip into the cups on the stand while the plate is suspended in the porous tube.

This apparatus permits the exchange of each of its constituents in an instant, and in trying various liquids there is little disturbance by endosmose, as the two porous cells containing them are immersed in a bath of intervening liquid: for experiments with manganese, sulphate of mercury, &c., a porous cell is needed for each substance; and with nitric acid and other oxidizers, &c., a clean carbon must be used for each, but platinum is better, if washed and made red hot.

579. ENERGY AND MATTER.—Some of the general relations of force to matter have been examined, §§ 17 and 163; we have now to study more closely how energy and force become electric energy or E M F. We must remember that each atom and each molecule of matter involves as part of its inherent nature an amount of energy as definite as of matter, but unlike the matter, not permanent in all changes; it is definite and fixed only for a definite and fixed condition, and for every change a definite change takes place in the amount of fixed energy. We must therefore, regard energy, as—

(1) *Fluctuating*, such as the sensible heat of substances, which enters and leaves them according as they are surrounded by bodies of greater or less temperature, but which does not change either their physical state or chemical properties.

(2) *Fixed*, associated with matter. Such is *latent heat*, now termed, *potential energy*; the most definite idea will be obtained of it by treating it as an amount of energy linked to the atoms and molecules of matter, and inseparable from them without change of nature or physical state, the mode of charging being the imparting of internal motion.

Each substance requires a definite amount of energy to pass from one physical state to a higher, as from solid to liquid and gaseous; and at each such change a definite amount of energy disappears, becomes charged on the molecules, i. e. is converted into latent heat or potential energy.

580. *Intrinsic or specific* energy, § 585, is also fixed and an inherent of each state of chemical union: every elementary atom has its proper energy, and the importance of this view will be seen when we find that the degree of this energy is really the measure and the cause of the chemical *affinities* of this atom. Every chemical action which occurs under the influence of affinity, that is every act of *combination*, is attended with loss of energy, i. e. the potential energy is set free, and becomes active and sensible in some form, either as heat,

electricity, or motion. On the other hand, every act of decomposition (the reversal of affinity) requires a supply of energy exactly equal in quantity to that set free by the act of combination, and this energy is again charged upon the atoms or molecules, and disappears—without it the change cannot occur.

581. To make all this really clear, and to attach to our chemical symbols their value in energy as well as matter, is at present impossible, as the data are not yet sufficiently ascertained, notwithstanding the labours of Favre and Silbermann, Andrews, and more recently of Thomsen and Berthelot. The latter author has published a work on Thermo-chemistry in which the most ample information is contained. But we can only regard the measurements as still merely approximate. As their figures are given in the metric system and often as related only to grammes or pounds, I have reduced the most important of their information into the equivalent in grains for matter and the foot-pound for energy. I may here remark that I have not altered the figures given in former editions, for the reasons given above, and in § 579. In the course of time, the actual figures I give will no doubt require to be somewhat altered, but readers should understand that this will in no way affect the principles involved.

582. MECHANICAL EQUIVALENT OF HEAT.—As a consequence of the doctrine of conservation of energy, the various forces (which are forms of energy) may be expressed either in a single measure or in terms of each other. Experiment has proved this for heat, and shown that a definite quantity of heat is actually transformed into a definite quantity of mechanical work; that is to say, that a pound of water raised in temperature so many degrees Fahr. or raised so many feet against gravity, means the same energy expended or stored. What the exact quantity is, is a matter for experiment of a very difficult nature, and therefore the exact value is not really known. The following is a list of several determinations by different processes in terms of the gramme-metres equivalent to the calory.

Hirn	Friction of water and brass	432
„	Crushing of lead	425
„	Specific heat of air	441·6
Regnault	Velocity of sound	437
Clausius	General properties of air	426
Favre	Electro-magnetism	443
Clausius	Heat of current in wire	400
Joule	„ „	429·3
„	Friction	423·55

This latter value represents 772 foot-lbs. per lb. deg. Fahr. of water, and is generally accepted by engineers. Another value is used, chiefly for arithmetical reasons; 42 million "ergs," written as 42×10^6, is a handy figure, and is being adopted; its value in gramme-metres per calory is 427·87, and the foot-lbs. per English heat unit 779·88. The value used in these pages is 772 foot-lbs. and its equivalent in the metric system. It is proposed to call the heat unit a "therm," as there is some confusion in the use of calory, which some writers apply to the kilogramme-metre; then if the mechanical equivalent is taken as $4 \cdot 2 \times 10^7$ ergs, we have 1 therm = 4·2 joules.

583. Relations of Units.—As different systems of measurement are used in different works, and in most scientific books the metric system is used, and may not be understood by all readers, I have worked out Table XVII., p. 314, which, subject to the remarks § 579, shows the mode of converting the values in one system into those of others. I have selected those figures which have proved most useful in my own experience. It should also be remarked that the values here are in slight degree different from others to be found in the work, as in the case of the calory, lines 22 and 23. The reason is that the C.G.S. system being based upon definite principles, it is desirable to have the values which are thus theoretically correct: but as neither the ohm nor the ampere, nor in fact several observed data are exact to the C.G.S. system, these other values may be even more correct in practice, and the differences are not great. The values of the joule, lines 24, 26, 27, on the grain system are here based upon line 23; the theoretical value, while in the body of the work figures may be found based upon line 22, the practical accepted value. The values are as correct as circumstances allow. Different writers call the gramme = 15·438, 15·434, 15·43235 grains, and give the calory unit of heat different values according as it is related to water at 0° or 4° Cent. This name, *calory*, is also given to two values; the original unit, and the value always meant in these pages, is 1 gramme of water raised 1° Cent., but it is often used to mean 1000 grammes. I have given the logarithms, which are more exact values than the decimals, so that the operations given can be reversed by subtracting instead of adding, or by adding the reciprocal of the logarithm (i. e. the log subtracted from 0·0000000), a process often useful also to enable an intricate calculation to be worked out by one final act of addition.

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.. Velocity o
.. General p
.. Electro-m
.. Heat of c
..
.. .. ”
.. .. Friction

584. The mode in which the figures are obtained, and the plan of using them, will be best seen in an example. Andrews gives the heat of combustion of zinc in oxygen as—

			Log.
Calories per gramme ..	1330		3·1238516
Equivalent of zinc	32·6		1·5132176
Calories per gramme equivalent			4·6370692 = 43358
Ratio of grain equivalent Table XVII., line 9	·198547		$\bar{1}$·2977983
Foot-lbs. per grain equivalent			3·9348675 = 8607·5
1 lb.	7000 ..	3·8450980	
Zinc	32·6 ..	1·5132176	2·3318804
Foot-lbs. per pound		.. ..	6·2667479 = 1,848,195

Owing to the various differences, this latter value is sometimes given as low as 1,463,925 per pound.

585. Intrinsic or Specific Energy.—These terms are both used by different authors to describe that quantity of energy which is definitely associated in each particular combination of atoms into molecules, § 570 (2). It is the essential agent of chemical relations, and is really the measure of *chemical affinity*. In fact this "intrinsic energy" is exactly what the earlier chemists very justly imagined the existence of as necessary to the explanation of combustion; only, according to the fashion of that age, they invented a special form of matter—a fluid—which they called *phlogiston*, to the gain or loss of which they attributed chemical actions. Nowadays we invent any required property of the ether, when we want to explain what we do not understand. In principle they were more true to nature than the school which succeeded them, for, after all, *phlogiston does really exist*, only it is not a thing, a fluid, but *energy* charged upon the atoms and molecules of matter.

As a fact, now well known, that affinity is strongest which sets free most heat in calorimetric experiments. Until late years this was not understood, and chemists confined their attention to the material atoms. But we have in *isomeric* bodies the evidence that something besides matter is concerned. There are many pairs of substances which contain exactly the same elementary proportions, but in which the molecule contains double or more of all the atoms in one case than in another. But beyond this there are pairs of substances exactly alike in material constitution, though belonging to different types, § 12; these, however, differ in intrinsic energy, and if equal weights are burned they do not give off equal heat. A great deal of work has been done of late years in this direction by Julius Thomsen and Berthelot, § 581, and the latter has based upon the facts of intrinsic energy a general law of chemical affinity, which he calls the law of *maximum work*, viz. "*All chemical action not due to external energy tends to the production of the body or bodies which set free the greatest heat.*" It will be seen that this is the counterpart of the general law of electrolytic action first explained in the first edition of this work, that those substances are set free by the electric current which *absorb the least quantity of energy.* As the energy of chemical action is definitely related to the E M F set up, it will be seen, § 599, that it is convenient to call that energy by the distinct name of "voltance," instead of vaguely "intrinsic or specific" energy.

We have now to study the mode in which the transfers of intrinsic energy, which is *potential* in the molecules of matter, result in chemical and electrical effects when it becomes *kinetic.*

586. Combustion.—The act of combustion or burning is the most familiar instance of chemical combination, while it is the complete illustration of the potential, latent intrinsic energy becoming active or kinetic, and taking the form of heat. At present we may consider it as simply combination, the union under the influence of chemical attraction of atoms of carbon, or hydrogen, &c., and atoms of oxygen. There really is also a decomposition of the molecules of these bodies, but that we are not now in a position to estimate. Now, as it is a fundamental maxim that we can create neither matter nor energy, and as this action gives us available free energy in the form of heat—where does it come from? Evidently from the atoms entering into union.

$C + O_2 = CO_2$ is the symbol of burning carbon, producing carbonic acid (or more properly anhydride), and $H_2 + O = H_2O$ hydrogen burning into water, but these symbols give us no information as to the source of the energy. It is, however, evident that before combination there existed a force tending to cause union, which we call affinity, and that when the union is effected, the resulting substance must have within it less combined energy than its components had before, because the act of union had set energy free as heat. This is usually treated as a mere incidental consequence of the affinity; however, it bears an exact ratio to the chemical force, and may be made to give meaning to the old diagrams of elective affinity. By fixing attention upon it, as the "intrinsic energy," capable of exact estimation, instead of the vague "affinity," we shall better understand the facts. Thus, using the equivalent notation, the burning of carbon is—

$$\left.\begin{array}{l}\underset{6}{C}+\underset{8}{O}=\underset{14}{CO}\end{array}\right\}+2946\text{ foot-lbs.}$$
$$\left.\begin{array}{l}\underset{6}{C}+\underset{16}{O_2}=\underset{22}{CO_2}\end{array}\right\}+9624\text{ foot-lbs.}$$

Here the energy of combustion is expressed in foot-lbs.; it is the "intrinsic energy," the measure of the force which holds together the atoms composing carbonic oxide, CO, and carbonic acid, CO_2; not wholly so, however, as the great difference between the two figures is due to the fact that portion of the energy of the first atom of oxygen is absorbed in converting solid carbon into a gas. We cannot be sure that all the four centres or valencies of carbon, § 9, possess equal specific energy, or we might calculate the latent energy of gasification of carbon from that given by complete combustion; but in examining actions under the influence of electricity, light will be thrown on this.

587. SALTS.—Combustion or oxidation is only one step in chemical combination, for almost all the substances used in electricity are salts, this term really including acids. The older view of salts, Berzelius's electro-chemical theory, supposed the first step to be oxidation, forming substances which were either acids or bases, according as the element ranked in the electric scale, and partly, also, according to the number of oxygen atoms combined, and these two bodies, preserving their original electric relations, combined to form salts. Although this theory is abandoned, it has still, so far, a real basis of truth, that the chemical attractions of the elements do in great degree correspond with this arrangement, which so far survives in the new chemistry that the old electro-negatives are still called chlorous or acid radicals, and electro-positives basylous radicals.

Chemical considerations, and especially the behaviour of acids and salts under the action of the galvanic current, led to the adoption of the binary theory, which treats them as composed of two radicals, of which the acid, or chlorous one, is a compound containing the whole of the oxygen, while the basyle is an element or a compound having properties analogous to those of elements. On this view the formulæ of sulphates are,

$$\left.\begin{array}{l}H^2,SO_4\\Zn,SO_4\\K_2,SO_4\end{array}\right\}\text{ instead of }\left\{\begin{array}{l}H_2O,SO_3\\ZnO,SO_3\\KO,SO_3\end{array}\right.$$

the acids being salts of hydrogen, which are displaced by other atoms possessed of higher "specific energy." This theory accords thoroughly with all the facts of electrolysis, and is that to which belong all the formulæ used in these pages. The older view of salts has, however, a present use in calculating the specific energy of acids and salts, as in § 589.

Returning to the constitution of salts on the old theory: SO_3 (four highly negative atoms) unite to form a strong acid, sulphuric (now called sulphuric anhydride); hydrogen as H_2O forms a weak base—water; while ZnO forms a stronger; and potassium, K_2O, the strongest base. By combining again, $SO_3 + H_2O$ forms ordinary sulphuric acid, from which the stronger bases can displace the water, forming in turn SO_3ZnO, and SO_3K_2O, sulphates of zinc and potassium.

588. INTRINSIC ENERGY OF ELEMENTS.—The foregoing principles may now be applied by aid of Table XIII., p. 308, in which I have collected the most important information as to the principal elements employed in electricity. Cols. I., II., and III., are the names, symbols, and atomic weights on the new notation, § 11; IV. the old chemical equivalent, which is also the weight taken in grains, to which Columns VII. and VIII. refer; V. is the valency, § 9; VI. shows the weight corresponding to one unit of electrical quantity, the chemic, § 170, varying where two classes of salts are formed; VII. is the energy of union with oxygen; and VIII. that with chlorine, of the equivalent in grains, Column IV. These two columns are the specific energies, § 585, of these chemical combinations. In some cases two values are given; they are different results obtained by Andrews (the upper row) and by Favre: the same remark applies to the other similar tables. Column IX. is the electric equivalent, in grammes, of the coulomb, or the ampere-second, as to which see § 422.

It is commonly stated, on the authority of Faraday's early experiments, that electricity, passing through solutions, acts in the *ratio of the several equivalents* (Column IV.). This is not the case; this view of *the equivalent of electricity* is based upon the accidental nature of the experiments. The truth, which became manifest only as the modern chemical theories were developed, is shown in Column VI.; the quantity of any element released depends, not upon its equivalent merely, but upon the state of combination in which it exists, that is to say, the valency of the radical it forms. Of course these are the theoretical values: they are not actually obtained in electrolysis, because there are wasting actions of acids &c., in practice. But as these vary under different conditions, it is useless to take account of them when treating of principles, § 859.

TABLE XIII.—ELEMENTS AND THEIR PROPERTIES.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
Name.	Symbol.	Atomic Weight.	Equivalent.	Valency.	Electric Equivalent.	Intrinsic Energy. Foot-lbs. per Grain Equivalent.		Coulomb equivalent in Grammes.
		New.	Old.			Oxygen.	Chlorine	Silver = ·001118.
ALUMINUM ..	Al	27·5	13·7	3–6	9·17	..	..	·000094936
CARBON ..	C	12·	6·	4	..	2946 9624	as CO as CO_2	..
CHLORINE ..	Cl	35·5	35·5	1	35·5	..	..	·00036749
COPPER (*ic*)	Cu	63·5	31·75	2	31·75	4802 4345	6036 5861	·00032867
„ CUPREOUS	Cu_2	127·	..	2	63·5	..	..	·00065735
GOLD (*ic*) ..	Au	197·	197·	3	65·7	..	..	·00067855
„ AUROUS	..	..	..	1	197·	..	..	·00203933
HYDROGEN	H	1·	1·	1	1·	6726 6841	4802 4721	·000010352
IRON (*ous*) ..	Fe	56·	28	2	28·	6565 751[illegible]	6491 9857	·00028985
„ FERRIC ..	Fe_2	112·	..	6	..	..	..	..
LEAD	Pb	207·	103·5	2	103·5	.. 5494	.. 8880	·00107142
MANGANESE	Mn	55·	27·5	2–6	..	..	..	..
MERCURY (*ic*)	Hg	200·	100·	2	100·	.. ..	5793 ..	·00103519
„ MERCUROUS	Hg	..	..	1	200·	..	..	·00207038
NICKEL ..	Ni	59·	29·5	2	29·5	..	..	·00030538
NITROGEN ..	N	14·	14·	3	4·7	..	..	·00004865
OXYGEN ..	O	16·	8·	2	8·	..	..	·00008282
PLATINUM (*ic*)	Pt	197·	98·5	4	49·25	..	..	·00050983
POTASSIUM	K	39·	39·	1	39·	.. 15135	20740 19996	00040372
SILVER ..	Ag	108·	108·	1	108·	.. 1214	.. 6908	·00111800
SODIUM ..	Na	23·	23·	1	23·	.. 14593	.. 18785	·00023809
SULPHUR ..	S	32·	16·	2–6	16·	.. 3526	— —	·00016564
TIN (*ous*) ..	Sn	118·	59·	2	59·	6654	6297	·00061076
„ STANNIC	..	..	..	4	118·	..	..	·00122155
ZINC	Zn	65·2	32·6	2	32·6	8394 8427	10080 9985	·00033746

589. Combination of Radicals.—It is evident that whether we call the formula of zinc sulphate, ZnO,SO_3, or Zn,SO_4, we have the same number of atoms, and, let them have come together how they may, the ultimate result is the same. Now we can actually build up this molecule on the first formula; that is, we can dissolve the oxide of zinc in sulphuric acid, while we cannot on the second formula, because SO_4, the sulphuric radical is not capable of uncombined existence. We are thus able to get at the intrinsic energy of the sulphates indirectly, by first ascertaining the heat of oxidation, and then that of solution of the oxide in acid; we thus get the total energy, but only approximately, as we cannot separate from the total the energy due to change of physical state. Table XIV. gives the result in foot-lbs. of the experiments of Andrews and Favre, arranged as in Table XIII.; the differences indicate the difficulties of the process.

Table XIV.—Energy of Combination of Oxides and Acids.

Oxide of.	Sulphuric.	Nitric.	Hydrochloric.
Ammonium	2759 2916	2422 2715	2422 2687
Copper	.. 1533	.. 1271	.. 1274
Iron..	.. 2158	.. 1915	.. 1951
Lead	..	1767 1834	.. ..
Potassium	3157 3193	2898 3079	2839 2989
Silver	..	.. 1370	.. ..
Sodium	3216 3139	2779 3034	2918 3003
Zinc..	2343 2076	2041 1652	2104 1649

590. In the case of chlorides there is a certain complication, as several actions have to be considered. (1) The actual combination of HCl, which Table XIII. Column VIII. gives as 4721. (2) As this is a gaseous body, its union with water gives further 3258 in forming the actual acid. (3) The heat of oxidation. (4) The union of acid and oxide. But we have now two products, the salt and water, and therefore the heat of this latter must be deducted to ascertain the energy of the

salt itself; and this again includes the heat + or − as the case may be, of the act of solution of the salt.

1. HCl	4721	7979
2. Solution	3258	

The formulæ (equivalent notation) now give the several further stages, taking for examples zinc and sodium:

$$\overset{a.}{\mathrm{ZnO}} \overset{b.}{+} \overset{c.}{\mathrm{HCl}} = \overset{d.}{\mathrm{ZnCl}} + \overset{e.}{\mathrm{HO}}.$$
$$\mathrm{NaO} + \mathrm{HCl} = \mathrm{NaCl} + \mathrm{HO}.$$

a. XIII. = ZnO	8427	NaO	14593
b. XIV. =	1649		3033
c. Above	7979	HCl	7979
	18055		25605
e XIII.	6841	HO	6841
d. ZnCl	11214	NaCl	18764
Solution +	1242	—	103
	9972		18867

The last figures agree closely with those of the anhydrous chlorides, of which the zinc gives out heat in dissolving, and the sodium produces cold.

591. I have in this way calculated the salts in solution, and Column III. Table XV. is the energy thus obtained of the several chlorides, while Column IV. is the energy developed *by simple* combustion in chlorine gas. In this table I have

TABLE XV.—ENERGY OF PROTO-SALTS.

I. Basyl or Metal.	II. Sulphates.		III. Chlorides.		IV. Chlorides by Combustion.
	Ft.-lb. per gr. equivalent.	Equivolts. E M F.	Ft.-lb. per gr. equivalent.	Equivolts. E M F.	
Copper ..	5878·	1·258	6857·	1·467	5861·
Hydrogen ..	8917·	1·919	7979·	1·707	4523·
Iron	9668·	2·069	10599·	2·268	9857·
Zinc	10503·	2·248	11214·	2·400	9985·
Sodium ..	17732·	3·795	18764·	3·996	18785·
Potassium ..	18328·	3·913	19262·	4·121	19996·

given the energy in equivolts as well as foot-lbs., for use in after calculations. A similar process would, in the case of sulphates, be more accurate than the one employed, if we know the real energy of formation of SO_3, because, when uniting the acid and base we form water, as well as the salt. I have omitted nitrates, because the reactions vary greatly, and full data are not attainable.

592. Is it not obvious that, by attaching figures like these to chemical symbols, we give them a new meaning and force? If the principle were fully carried out, how clear reactions would become. Why do iron and zinc decompose sulphuric acid while copper and silver do not? The tables answer us; the intrinsic energy, i.e. the attraction of copper and silver for sulphuric radical SO_4 is less than that of hydrogen in the proportions shown, while that of iron and zinc is greater. If the deficient energy is supplied by heating, then copper and silver will react upon the acids: for the same reason nascent hydrogen or sulphuretted hydrogen can precipitate the metals above hydrogen in the list, but not those below, in acid solutions.

593. SUBSTITUTION OF BASES.—If, instead of directly combining two radicals, we substitute one for another, the force of the reaction will be equal to the difference between the attractions; and thus, if we exchange radical for radical in a descending series, at each step we get an instalment of energy set free, and it is found that these instalments bear a distinct relation to the electromotive force of batteries so constituted. The action of the Daniell's cell, which is a convenient starting-point for measurement, is the substitution of zinc for copper in the sulphate, for zinc is dissolved at one plate, and copper deposited at the other: the energy, therefore, is according to the tables

Sulphate of zinc	10503
„ „ copper	5878
	4625

(1·079 × 4673 = 5042).

Andrews gives 5450 as the results of his experiments, which represents 1·167 volt as the E M F. It is probable that the different solubilities of the two salts is the cause of the differences.

Present knowledge is not sufficiently perfect to enable us to rely much on any of these figures, but it is generally considered that the E M F of this reaction of the Daniell cell is 1·079 volts, and Table XVI., with the preceding ones, will give readers pretty well all the information at present attainable;

the data are those of Andrews and Favre, and in the last column I have calculated the forces in volts, as compared with that of the Daniell taken as datum.

TABLE XVI.—FORCE OF DISPLACEMENT OF METALS.

Metals Displaced.	Metals Substituted.			Calculated in Volts.
	Lead.	Iron	Zinc.	Zinc.
Platinum	..	..	17605	3·485
Silver	..	..	9127	1·807
	9389	8454	9414	..
Mercury	..	..	6616	1·290
Copper	1685	3719	5450	1·079
	..	3331	6158	..
Lead	..	..	3743	·741
Hydrogen	..	..	3676	.730
		2827	3662	..

594. ELECTROMOTIVE FORCE AND INTRINSIC ENERGY.—Having now ascertained the energy of the various reactions employed in electricity, we have next to discover how this energy is changed into an electric force, and to do this we must first ascertain the value in foot-lbs. represented by the volt—the measure of electric potential or pressure. Now it is obvious, § 482, that this being a static measure, can no more be expressed by itself in foot-lbs. than can a ton weight resting on the ground; with the pressure must be united time or motion, as in mechanics.

Just as the attraction of gravity, acting through a unit of space, furnishes the mechanical unit, the foot-lb., so a unit E M F, a volt, acting through a unit resistance, an ohm, will give us a unit of electric energy if we employ some unit which shall correspond to the pound in the mechanical unit. This must be something answering in electricity to the idea of "quantity," as the pound represents the analogous idea of *mass* in matter. As shown, § 404, the only proper value is that quantity of matter to which Nature herself connects electricity, viz.—

$$\frac{\text{Atom}}{\text{Valency}} = \text{electric equivalent.}$$

Any system of weights may of course be used, but as part of the definite system of this book, I must of necessity use here, to make the principles clear, that weight—the grain equivalent which holds to my *chemic* current the relation which the coulomb holds in the B.A. system to the *ampere* current.

595. An ampere of current is the effect of one volt in a circuit of one ohm during one second, and this current is equal during the same time to 5·68 chemical units, or in ten hours produces 5·68 equivalents of chemical action in grains; that is to say, an ampere current maintained for 6338 seconds (or 6338 coulombs) corresponds to a chemic current maintained ten hours, and represents 1 grain equivalent of electric quantity.

596. The energy developed in or absorbed by a circuit is in the ratio of the square of the current; it may be measured as heat, or in mechanical units and the value for an ampere under unit conditions is in calories ·24065, which for ten hours gives

Ampere equivalent, calory ·24065	$\bar{1}$·3813859
Calories to foot-lbs., 3·0636	0·4862300
Ten hours = 36000 seconds	4·5563025
Foot-lbs.	4·4239184 = 26544
÷ 5·68	0·7543483
Foot-lbs. per volt equivalent	3·6695701 = 4673

Ten hours divided by 5·68 gives us 6338 seconds as the number of coulombs required to effect one grain equivalent of action. Hence we get by the absolute system

Work of ampere, C.G.S. units, ergs 10^7	7·000,000
C.G.S. unit in foot-lbs.	4·8676563
6338 seconds	3·8019447
Foot-lbs. per 6338 ampere-seconds ..	3·6696010 = 4673

The same result may be obtained in a variety of ways, and each of these calculations (experiments made in figures) furnishes some *data* which, with others similarly obtained, I have transferred to Table XVII. for use in other cases. This result is of supreme importance, for it gives a definite meaning to the volt, which has hitherto been too ideal to grasp.

597. THE EQUIVOLT.—This is the name I proposed for the unit just arrived at, which unites the ideas of *quantity*, *force*, and *energy*, and connects them as a definite value with the atomic theory and notation of chemistry, and will act as the unit of the correlation of forces. The name is compounded from the "equivalent" as the basis of quantity, and the volt as that of potential. The name has not caught on, and the idea, in this concrete form is not received by the professors and mathematicians, probably because it makes too clear the absolute

TABLE XVII. VALUES OF CONVERSION OF UNITS.

Name of Unit.	Value in	× Decimal.	+ Logarithm.
1. Metre	Feet	3·28089	0·5159894
2. Ditto (millim. to mils) ..	Inches	39·37042	1·5951706
3. Millimetre square	Circular mils ..	1973·56	3·2952503
4. Gramme	Grains	15·432	1·1884317
5. Gramme-metre	Foot-pounds ..	·007233	¯3·8593253
6. Calory (gm.-deg.-Cent.) }	Foot-pounds ..	3·0636	0·4862300
7. Ditto .. .. .. }	Gramme-metres	423·55	2·6269047
8. Ditto (mec. equt. = 427·87)	Ergs (see 12) ..	42,000,000	7·6232493
9. Ditto per gramme or .. }	Ft.-lbs. per grain	·198547	¯1·2977983
10. ,, equivalent .. }	Equivolts ditto ..	·0000425	¯5·6281909
11. Centigrade Thermo. (+32°)	Fahrenheit	1·8	0·2552725
12. Gravity Force of (*g*) ..	Dynes (say) ..	981· {	2·9916690
13. C.G.S. unit the *erg*	Gramme-metre ..	·0010194 {	¯3·0083310
14. Ditto ditto	Foot-pounds ..	·000007373	¯6·8676563
15. Ampère current	C.G.S. unit ..	10^{-1}	¯1·0000000
16. ,, or coulomb equivalent	Gram. × equiv.	·000010222	¯5·0095453
17. ,, or coulomb per second	Chemic	5·68	0·7543483
18. Chemic current, 10 hours	Coulombs	6338·	3·8019447
19. Ditto do. Work of (equivolt)	Foot-pounds ..	4673·	3·6696010
20. Joulad (volt-ampère) }	Ergs	10^7	7·0000000
21. ,, $C^2 \times R$ } as work }	Foot-pounds ..	·73732	¯1·8676563
22. ,, $E \times C$ } as heat }	Calory	·24065	¯1·3813859
23. ,, Theoretical }	Ditto, line 8 ..	·23895	¯1·3767507
24. ,, × time of grain equt. (18)	1 Equivolt = ft.-lbs.	4673·	3·6696010
25. ,, ditto of gramme ,,	,, Calory system	23287·7	4·3671271
26. ,, heats (water ÷ sp. heat)	{ Grain degree Fahr.	6·6139	0·8204549
27. ,, ,, copper	{ ditto, by line 8 ..	65·29	1·8148455
28. ,, Sp. Res. cub. cent. ..	R per mil-foot ..	6015350	6·7792609

RATIOS.	π = Circumference to diameter	3·14159	Log	0·4971499
,,	square and circle of equal diam.	1·2791		0·1049091
,,	square area of circle	*d*2 × ·7854	,,	¯1·8950909
WEIGHT *of water.*	1 cubic centimetre = 1 gramme		,,	0·0000000
,, ,,	1 cubic inch .. grains	252·458	,,	2·4021857
,, ,,	1 mil-foot .. ,,	·0023793	,,	¯3·3764578

,, *of liquids and solids.* × by specific gravity.

,, *of gases and vapours* at 0° Cent. and 760· mm. Bar.

1 cub. dec.-met. = 1 litre or

,, *of Hydrogen*	= (1 crith) gramme	·089578	,,	−2·9522014

,, of others, multiply by *half the atomic weight.*

WIRES. Copper { *mil-foot.*	weight in grains (M)	·0211761	,,	−2·3258478
,,	resistance (pure) at 60° F. (U.)	10·3365	,,	1·0143726
,, ,,	correction per deg. F. × by deg.	1·00215	,,	0·0009327

NEW VALUE {	Coulomb equivalent	Gramme	·00001035	,,	−5·0150180
	,, ,, hydrogen	Grain	·0001598	,,	−4·2034497
,,	Ohm = 106·3 Cent.	B A unit	1·01358	,,	0·0058580
	B A unit.	Ohm	·9866	,,	−1·9941411

connection of electricity and energy to *matter*, and bars the way into the regions of the ether and abstract theory. But the idea itself is none the less universally received in a less definite form, and the equivolt itself is commonly used, only under the title of a "constant" in calculations, as will be seen in § 628. The equivolt then is—

(1) Energy equivalent to 4673 foot-lbs. exerted upon a polarized chain, each link of which is an "electric equivalent," § 465 under the strain of 1 volt electromotive force.

(2) The mechanical energy of 1 volt exerted under unit conditions through 1 grain equivalent of chemical action.

(3) The source of so many volts of E M F from any chemical reaction as 1 grain equivalent of that reaction will produce equivolts of energy; therefore the volt and equivolt are equal as to value, but not the same things; the volt is pressure simply, but the equivolt is pressure, time, and equivalence, i. e. energy.

598. *The Equivolt as the Unit of Correlation.*—The doctrine of the correlation of forces, or equivalent conversion of any one form of energy or "mode of motion" into others, is the grandest and most fruitful of all modern scientific achievements; its value is, however, obscured, and its work greatly limited by the system of using arbitrary units differing for every form of force. Those who have understood the principles involved in the previous sections of this chapter now see that the equivolt supplies the much needed common unit of measurement for the forces, but when thus used it will have to be expressed, not in terms of the grain-equivalent, but of the ampere-gramme equivalent as explained § 630.

It should be understood, however, that in the C.G.S. system the *erg* is to some extent a unit of correlation, as it expresses all forms of energy. But it does not and cannot fulfil the function of the equivolt, because it is a unit of *energy only*, and is not connected to the atom of matter.

599. *Voltance* is the definite name which I propose for that energy which is convertable into electric energy, and which produces that stress, action, or pressure, which we measure in volts and call *voltage*, § 499. It consists of the intrinsic or specific energy of constitution, §§ 580 & 585, and also of the energy, + or − as may be, of solution of substances; that is to say, it is that energy which is fixed upon and intimately associated with the *molecules of matter*. Here, then, we see the basis of the facts of current mentioned §§ 492–3, and the importance of studying the theory of these facts in the actual phenomena of nature, as presented by chemical action in batteries, rather than in the form of abstractions based upon the mere

functions of E M F as derived from a mechanical source: undoubtedly the action is the same ultimately, but in the case of the battery we are compelled to keep to nature, while in the other we may run riot among formulæ. We have here the two functions, *current* and energy, both originating from the one molecule of matter, and never dissociated throughout the circuit; the function of the molecular structure—the current, perpetuated through the whole circuit unchanged, because it is essentially a phenomenon of the structure of matter, and the equivalence of atoms. The *energy* never separated from the molecules, which by their motions are the agents of its transmission, but gradually expended in those very motions, by transformation into heat, which leaves the circuit. This is just what happens in those manifest mechanical motions which, as we can actually observe them, enable us to comprehend these molecular motions, which are beyond our actual examination, as shown in § 491 and Fig. 58.

600. CONTACT AND CHEMICAL THEORIES.—Ever since the discovery of current electricity, two theories have been maintained as to its production. One school, following Volta, attributes the origin of current to a "force" due to the mere contact of the two bodies producing a disturbance in the normal distribution of electricity, assumed to be a constituent of all bodies, which, extending to neighbouring substances, sets up electric and chemical effects. The other school, following Galvani, has attributed this origin to the *reaction of chemical affinities.* Until recently nearly all English electricians have adopted the chemical theory, in the belief that Faraday had clearly demonstrated the baselessness of the contact theory.

But in our new source of electricity, the dynamo machine, we do apparently obtain enormous currents of electricity without chemical agency, and this may to some extent explain the revival of the contact theory. But it is certain that in these machines the source of electricity is in no way "contact," and when we look a little further we find that it may be traced to chemical action, because it is derived from the consumption of coal—that is to say, the chemical reaction of oxygen on carbon and hydrogen. The one thing, however, which these machines prove is that electricity is derivable from "energy."

601. The *contact theory* has undergone various changes; at first it was held that the force originated at the point of contact of *the two metals*, say copper and zinc. Faraday demonstrated the production of voltaic electricity when no metals were in contact, and by a number of proofs demolished the contact theory in this form, and established the chemical theory by proving

that no electricity was produced except as an *accompaniment of chemical action.* Then the contact theory was modified so as to include the *contact of all heterogeneous substances.* After a time the idea was added, that *contact is the source of the electric force,* but that chemical action was necessary to *maintain the electric current.* Brought into this compass, the question may be defined as being *whether electrical action arises from chemical actions occurring among the bodies present, or whether the chemical action arises because an electrical force is created by the contact of the bodies.* It must be admitted that, so stated, the question seems to be almost one of words, and that there is no practical difference between the two theories; the molecular theory adopted in these pages really combines the truths of the two others in one harmonious system, for it shows that electric polarisation tends to be produced whenever any two heterogeneous substances come into contact.

602. *This contact,* however, is no new mysterious force or "difference of contact potential," it is the ordinary *chemical* force of affinity, necessarily exerting itself upon *all* its surroundings, whether *within the molecule* constituted by virtue of its action, or *upon the external atoms* brought within its range by the contact, which merely means close neighbourhood, allowing force to distribute itself upon the universal law of the inverse square of distances.

Therefore this theory is really the chemical theory, and not the contact theory developed, and although it may appear, as before remarked, that this is a mere question of words, it is really one of great importance. The point is whether we have the right to invent some new *force* whenever we want to explain something, or rather to adopt some sounding word to wrap our ignorance in, and then offer that word as an explanation of facts we do not understand.

603. An experiment of Sir W. Thomson's is constantly quoted as proving the existence of "contact potential": it is a modification of the quadrant electrometer described § 75. Instead of opposite quadrants being charged + and – from an external source, they are themselves made of different metals in the form of half rings, and the moving plate is suspended over one of the openings: if any "contact force" exist between the two metals the needle remains at rest when they are separated, and moves when contact is made between them at the opposite ends of the half rings; this is exactly what happens whenever wires attached to the bars are made to touch. Here it may be remarked that this is precisely the same thing as making the metals themselves touch, *no matter*

what the material of the wires may be: both in this case and in thermo-electricity it is only the terminal metals which affect the result, because any intermediate junctions neutralize each other.

604. This experiment *proves the chemical theory.* Mr. J. Brown of Belfast repeated the experiment, and proved that the difference of potential set up varied in degree, *varied in direction,* according to the nature of the atmosphere bathing the open junction of the metals: the divided ring of two metals with the space between them constituting a pure galvanic cell, in which the relation of the *metals to each other* plays, if any, the most insignificant part, while their relation to *the gas to which they are exposed,* the chemical action set up, is the whole cause and measure of the effect.

605. Dr. Fleming's experimental battery was based on the same principle: he suspended bent strips of lead and of copper alternately in a series of glasses containing alternately nitric acid and pentasulphide of sodium, so that each vessel contained a strip of copper and of lead without any contact of different metals anywhere, but so that the chemical action, as related to the two metals, was alternately reversed, and the voltage generated by these actions was alternately from lead to copper and from copper to lead, resulting in one continuous E M F and current, absolutely independent of metallic contact, but due wholly to chemical energy.

606. We may put the facts into the form of a law. *Wherever there is free energy present* (as heat in thermo-electricity) or *wherever there is potential energy seeking to become free* (as where chemical affinities can come into play) *in presence of differential molecular structures or conditions, there energy takes the form of electric potential.* Voltance becomes voltage. The quantity of energy associated with any molecular conditions, or acting in the molecular chain measures the E M F due to the particular conditions. This is what is embodied in my equivolt, and it is known and admitted even by those who maintain the contact theory. The generation of E M F in dynamo machines also depends upon the energy applied to moving the wires across a magnetic field, in which they are subjected to molecular stresses.

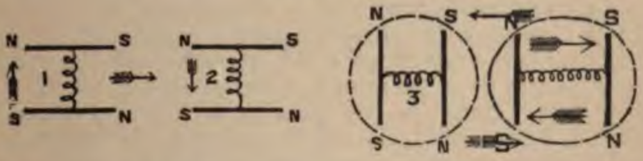
607. Even the difference of temperature of two parts of the same solution will set up E M F, just as it does in the thermopile: so will the act of solution, which itself generates either + or − heats, § 591; what is the same thing, a dilute and concentrated solution set up E M F at their junction, and in all cases this action is dependent on the direction in which heat

passes. In all cases we find EMF means transmission and change of form of energy, and we may now study the mechanism of the operation.

608. Transmutation of Energy.—Admitting the existence of atoms and molecules as described §§ 10, 131, and their possession of mutually attractive powers, varying in degree with their nature, it is evident that when different substances come within the range of their mutual attractions, they must exert a disturbing action on each other's constituent particles: those atoms in the two bodies which have the greatest attraction for each other will turn towards each other, and weaken, if they do not altogether overcome, the attractions which hold them in their original arrangement: the disturbance thus caused is propagated to the contiguous molecules; hence is produced a consecutive orderly arrangement called *polarization*, tending to complete a closed chain or circuit, owing to the action of the partially released atoms seeking fresh partners or points of union, § 465.

609. Galvanic Circuit.—We may find an illustration in magnetism. We may regard the atom as a small magnetic needle, the molecule, as two such needles mounted on a stem with their poles opposed, forming an astatic pair in which the attractions of the several poles satisfy each other; now, this needle being suspended freely, will be indifferent as to position, but if we bring a magnet near, the existing internal equilibrium is deranged, and the astatic needle will place itself in some position due to the external influence; the same will occur if we bring a second astatic or combined system near the first (they being capable of free motion in any direction)—they will arrange themselves as is represented by Fig. 65.

Fig. 65.



1 and 2 represent molecules held together thus by the forces of polar attraction of the atoms represented by spiral springs. When two such molecules approach, part of their forces act externally and hold the molecules together, though with a force less powerful than the internal affinity. 3 and 4 convey the

same idea more fully; in 3 the internal attraction is shown strong; in 4 it is weakened by part of the attractions being directed externally to the nearest, or most attracted, of the atoms of the approaching molecule. This is the action described throughout this work as *electric polarization*, to which the actions of electricity are chiefly due. This idea as to structure of matter, which I have long held as to matter generally, has been applied and very generally adopted as to magnetic matter: it is the basis of the most recent theory of Prof. Ewing, illustrated by his admirable experiments; which is itself also the theory of Prof. Hughes carried somewhat further into detail.

610. We may imagine a line of equidistant magnetic needles, which can turn on their axes but not change place.

$$\frac{N\;\;S}{+\;\;-}\qquad\frac{N\;\;S}{+\;\;-}\qquad\frac{N\;\;S}{+\;\;-}\qquad\frac{N\;\;S}{+\;\;-}\qquad\frac{S}{+}$$

Such a system would arrange itself in polar order, and on presenting a S pole (as S at the end of the row), each magnet would revolve and transmit motion along the line, or if the terminal magnet were moved a similar action would occur, and by it mechanical energy would be transmitted, losing itself partly on the way by friction; the more distant magnets would also have less effort exerted upon them, under conditions analogous to the fall of potential in a conductor, § 491.

611. A mechanical form of this idea consists of a row of wheels working into each other and all moved by energy imparted to the first one, which energy is transmitted along the row, each wheel moving on its axis without change of place. This conveys the two ideas of "quantity" and of work just as completely as does the transmission of a material bulk of water in a pipe: each rotation of the wheels is a measure of quantity as perfect as is the motion of a foot of water, and the energy transmitted will be as the square of the number of rotations in a given time. Here then we have, as in electricity and as in hydraulics, § 505, conditions corresponding to the number of turns (quantity) and the pressure applied (E M F), resulting in energy as C × E.

612. POLARIZATION BY POSITIVE METAL.—These ideas are readily transfered to the atoms and molecules of matter, for there is very great reason to believe that every atom is endowed with a species of polarity similar to that of the single needle.

A piece of zinc is immersed in sulphuric acid and the molecules in contact instantly arrange themselves thus:

$$\overbrace{\underset{-}{\mathrm{Zn}}\ \ \underset{+}{\mathrm{Zn}}}\qquad\qquad \overbrace{\underset{-}{\mathrm{SO_4}}\ \ \underset{+}{\mathrm{H_2}}}$$

one of the atoms of zinc attracting the sulphuric radical SO_4 and weakening the previous internal attraction of this for the hydrogen, which, with the second atom of the zinc molecule, similarly exerting external force, acts in turn upon other molecules, till a complete chain is formed through the lines of least resistance. This is fully shown as regards the Daniell cell, § 465, and in the single line,

$$-\ \overbrace{\mathrm{Zn.\ Zn.}}\ \ \overbrace{\mathrm{SO_4\ H_2.}}\ \ \overbrace{\mathrm{SO_4\ Cu.}}\ \ \overbrace{\mathrm{Cu.\ Cu.}}\ +$$

Zinc entering into solution and copper deposited setting free the differential voltance, § 593.

613. Actions at Negative Plate.—We have seen, § 591, that the total energy derived from zinc in sulphuric acid is 10,503 ft., or, the equivolt being 4673 ft., we may say that the gross voltage of zinc is 2·248, less deductions to be now ascertained. (1) There is the energy absorbed by the substance set free—copper in the Daniell; nitrous gases in the Grove and Bunsen, chromic alum in the bichromate (some of these may be simplified by regarding the process as the liberating of oxygen from prior combination), and most serious of all, hydrogen in the single acid cells. (2) There is the effect of the negative plate itself, and this has been generally overlooked, although it is well known that the E M F of a cell varies with the nature of the negative plate. The theory now under consideration will tell us why. We have seen the zinc polarizing the liquid, but on the same principles every metal would attract the acid radical, and tend to set up polarization; this means a struggle between the two metals for the possession of the sulphuric radical, and that the force developed in the chain is due to the *difference* of the two attractions, so that only the balance of the greater force is available to eject, say the hydrogen, at an expenditure of 6841 foot-lbs., leaving the residue to develop into E M F, and ultimately into work and heat. The total possible force of a Smee or similar cell is therefore—

Total force of zinc ..	foot-pounds	10503	= volts	2·248
Absorbed by hydrogen	„	6841	„	1·464
		= 3662	„	·784

and from this has to be deducted the counter effect of the negative or collecting plate.

614. Here we see the reason of the rapid failure of single acid cells, such as the Smee, § 201. The E M F tested so as to prevent its working, as by condensers or against high resistance, is much larger than this. Clark gives it as 1·098, and as only ·407 when working; the difference is probably the energy absorbed in rendering hydrogen gaseous; for under the first condition (high resistance and very small current) the hydrogen set free does not actually become a gas; it either forms a liquid (metal) film on the plate, or enters into a partial union with it, or is dissolved in the liquids, and the energy needed to gasify the hydrogen is available for E M F.

615. In estimating the counter force of the negative plate we require some starting-point to fix an actual value on what is otherwise only relative; the counter-force of carbon is so small that, in the general uncertainty of the figures available, we may count it as nothing, because, although a conductor like the metals, unlike them it cannot replace hydrogen as a base, or form salts with acid radicals; hence, properly treated, carbon gives the highest attainable force, and we may assume, without much risk of error, that the force it gives is that of the + metal, less only that of the substance set free at the − plate. This applies, however, only to nitric acid and similar cells, on account of the great capacity carbon possesses, like platinum, of condensing hydrogen upon its surface.

Taking the value of the nitric acid cells as given by Clark, Table XVIII., and expressing all the forces and actions in the equivolt, we obtain, as a starting-point, the force absorbed in decomposing nitric acid.

Total force of zinc	volts	2·248
Carbon in Bunsen cell	„	1·964
Force absorbed by nitric acid ..	„	·284

In the Grove cell, all the conditions being the same except that platinum replaces carbon, we have

Force of carbon	1·964
„ platinum	1·956
Counter force of platinum	·008

TABLE XVIII.—ELECTROMOTIVE FORCE OF CELLS IN VOLTS.

Name.	Positive Cell.		Negative Cell.		Authority.		
	Metal.	Liquid.	Metal.	Liquid.	My Experiments.	Clark and Sabine.	De la Rive.
1. Total force.. ..	Zinc	Sulphuric acid 1–12	..	..	2·248	..	..
2. Smee	,,	,,	Platinized silver	Dilute acid	1·107 ·508	1·098 ·482	·541
3. Wollaston	,,	,,	Copper	,,	·861 ·270	·886	·719 ·536
4. Bunsen	,,	,,	Carbon	Nitric acid: fuming	See Table XIX.	1·964	..
5. ,, ...	,,	,,	,,	,, specific gravity 1·38		1·888	..
6. Grove's	,,	,,	Platinum	,, fuming		1·956	..
7. ,, ...	,,	,,	,,	,, specific gravity 2·33		1·809	..
8. Bichromate ..	,,	,,	Carbon	100 water, 12 bichromate, 25 acid	1·905	2·028	..
9. Slater's	Iron	Spent solution	,,	Nitrate of soda and sulphuric acid	1·096	..	..
10. Marie Davy ..	Zinc	Acid 1–12	,,	Sulphate of mercury	1·542	1·524	..
11. Leclanché	,,	Sal-ammoniac	Carbon with manganese peroxide	Sal-ammoniac	1·561	1·481	1·942
12. ,, ...	,,	Common salt	,,	Salt	1·493	..	..
13. Daniell	,,	Sulphuric acid 1–4	Copper	Sulphate of copper	1·079	1·079	1·079
14. ,, telegraph	,,	1–12	,,	,,	..	·978	..
15. ,, ...	,,	,,	,,	Nitrate of copper	..	1·000	..
16. Silver chloride ..	..	..	Silver	Zinc chloride	..	1·195	..
17. Lead	..	..	..	..	..	·578	..
18. ,, sulphate ..	Zinc	Acid 1–12	Copper and lead	Sulphate of lead in acid	·550	..	..
19. ,, peroxide ..	,,	..	..	..	..	..	2·446
20. Grove's gas ..	Platinum	Hydrogen	Platinum	Oxygen	1·5	..	2·518
21. Chromate of lime	Zinc	Dilute acid	Carbon	Calcium chromate	2·070	..	..

These examples show the processes employed in calculating the following tables.*

616. Electromotive Force of Cells.—Table XVIII. is compiled from various sources, which differ very much. My own determinations, made for the calculations now being considered, were made with a sine galvanometer through a resistance of 1500 ohms, and with the apparatus described § 578. They only claim approximate accuracy.

617. Table XIX. shows the E M F of Grove's cell under different conditions; it is derived from Poggendorf, and is very instructive. The different force given by the acids in different degrees of dilution well illustrates the conversion of specific energy into electric force. As we mix the acid with water it develops heat, and this means loss of potential energy, therefore a diminished amount available for use; for the same reason heating the liquids increases the E M F. Still my own experiments do not show that this produces anything like the effect shown in lines 11 and 12 of Table XVIII., on the authority of Clark and Sabine; I find that the dilution of the sulphuric acid affects the resistance rather than the E M F.

Table XIX.—Force of Grove's Cell.

Zinc in Sulphuric Acid.	Platinum in Nitric Acid.	Force.
Specific gravity 1·136	Concentrated	1·955
" " 1·136	Specific gravity 1·33	1·809
" " 1·060	" " 1·33	1·730
" " 1·136	" " 1·19	1·681
" " 1·060	" " 1·19	1·631
Sulphate of zinc ..	" " 1·33	1·673
Common salt	" " 1·33	1·905

618. I have found, as shown in the last line, that salt with acid gives a higher E M F than sulphuric acid does, this being due to the reaction of the two liquids upon each other, which

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* There are peculiarities hitherto unnoticed in the behaviour of carbon and platinum as negatives. In some experiments I have used two plates of the same size in different reagents. In dilute acids and in chromic acid I found the E M F with carbon one-sixth greater than with platinum. But when the same plates were used in nitric acid, the platinum gave very slightly the greater force. This would indicate a source of the different results by different experimenters: the carbon is known to vary in quality and so does platinum, and besides this there is probably a different relation with each variation of quality, to the acid radicals of different excitants.

comes in aid of the zinc. It will, however, give higher *current* only when the external resistance is large, as its own greater resistance counterbalances the extra force it generates. A glance at Table XV. will explain this, as Col. III shows that the force of chlorides in solution is greater than that of sulphates except in the case of the acids themselves: the consequence is that sulphuric acid acts upon salt, metallic chlorides are produced together with sulphate of soda, and this extra force is added to that of the circuit, as it is in the same direction. For similar reasons HCl gives higher E M F than H_2SO_4, § 187.

619. Table XX. gives my own experiments on nitric acid and similar cells, as to the effect of different oxidizing agents, and of different metals as positives:

TABLE XX.—FORCES OF OXIDANTS.

I.	II.	III.	IV.	V.
Negative Cell.	Positive Cell.	Electromotive Force.	Total Force of Positive.	Loss by Reaction.
Platinum.	Sulphuric acid, 1 to 10 water.			
Nitric acid, sp. g. 1·324	Zinc	1·761	2·248	·487
"	Iron	1·184	1·671	"
"	Copper	·786	1·273	"
"	Silver	·678	1·165	"
Nitrate of soda and sulphuric acid	Zinc	1·540	..	·708
"	Iron	1·096	..	..
Bichromate of potash ..	Zinc	1·905	..	·343

620. FORCE OF POSITIVE METALS.—From the force given by each combination in Table XX., and using the force of zinc already obtained, § 591, as the starting-point, the value of other metals is readily arrived at. Taking 2·248 volts or equivolts as the total value of zinc, the actual force generated under any given conditions gives the loss, or force absorbed by these conditions. In the Grove we have 2·248 − 1·761 = ·487; all the conditions, except the positive metal, remaining unchanged, this is a constant loss, and by adding the actual force each metal yields, we obtain the total force that metal can generate. Table XXI. gives the results of several such processes, and also the value derived from Favre's figures of the sulphates.

TABLE XXI.—FORCE OF POSITIVE METALS.

Single cell.	Zinc.	Iron.	Copper.	Silver.
Table XXIII., Col. II. ..	2·248	1·723	1·280	1·174
Daniell's	,,	1·702	..	..
Grove's, XX., Col. IV. ..	,,	1·671	1·273	1·165
Favre, XV.	,,	2·069	1·258	..

These figures agree among themselves more closely than those given by different authorities for the same experiments; but iron presents an anomaly, owing, probably, to its capacity for forming two sets of salts. However, while Favre's figures make its value 2·069, Andrews' give it as 1·888, so there is obviously room for further information.

621. COUNTER FORCE OF NEGATIVES.—It was pointed out in § 613 that while the chemical action at the positive metal is the source of E M F there are two actions at the negative plate which diminish this force; the first to consider is the opposing power of the negative plate itself. This can be ascertained, like the positive force, by keeping all conditions constant except the negative plate. Table XXII. gives the forces produced by both sets of changes at one view.

TABLE XXII.—FORCE OF METALS IN SULPHURIC ACID.

Negatives.	Positives.			
	Silver.	Copper.	Iron.	Zinc.
Platinum	·293	·399	·842	1·367
Silver	..	·139	·582	1·107
Copper	..	..	·236	·861
Iron	..	..	..	·558

The platinum line and zinc column are the observed figures; the others are calculated from them. The forces are those produced against such resistance as prevents the formation of gas; by deducting ·583 from them we get the force under working conditions (§ 613), though here, again, iron shows a discrepancy, as it would appear that iron and zinc would not produce a working current, though in fact they do.

As the full force of zinc is 2·248, and 1·367 is the highest actual force, we have 2·248 − 1·367 = ·881 as the constant quantity to deduct from the total loss which each negative metal shows in the same way with zinc; thus silver and zinc give 1·107, which, taken from 2·248, leaves 1·141 − 881 = ·260 as the counter force of silver. In this way Column III. of Table XXIII. is obtained.

I may here remark that platinized silver acts precisely as silver so far as the force is concerned; its value is in throwing off the gas, and so diminishing resistance; and hence it would appear that it is more economical in the long run to use platinized platinum than the cheaper silver.

Columns IV. to VII. of Table XXIII. show the net force due to the metals; deducting the counter effect of the negative plate, but not of any chemical reaction, which is considered in next section. Some writers say that this relation is constant for all liquids, but this is not so; it is a matter of chemical reaction, and the relations may even be reversed; thus iron is positive to copper in acids, but copper is positive to iron in sulphide of potassium and other liquids. See § 605.

The figures in the table are based on sulphuric acid, but are approximately correct for all the ordinary combinations, as may be seen by Table XXI.

TABLE XXIII.—FORCE OF METALS IN VOLTS.

I.	II.	III.	IV.	V.	VI.	VII.
Names.	Total as Positives in Sulphuric Acid.	Counter Force as Negatives.	Force of Positives as Opposed to Column I.			
			Zinc.	Iron.	Copper.	Silver.
Carbon	0	0	2·248	1·723	1·280	1·174
Platinum ..	(?)	·008	2·240	1·715	1·272	1·166
Silver	1·174	·260	1·988	1·455	1·010	..
Copper	1·280	·506	1·742	1·209	..	..
Iron	1·723	·809	1·439	..	..	..
Zinc	2·248	..	0	..	..	..

622. CHEMICAL COUNTER FORCE AT NEGATIVE PLATE.—The second deduction from the E M F is the chemical action in the liquid at the negative plate. In § 613, setting hydrogen free is set down at 1·464 equivolts; this is an excess, no doubt, for it is the force of combustion of hydrogen, which includes the latent heat of gasification of oxygen; in work, however,

batteries appear to absorb this, for the counter force of hydrogen, coating the plate makes it up. Taking the force when hydrogen is not set free as gas, we may obtain the latent heat or energy of gasification

Force of Smee observed	1·107
" silver zinc, Table XXIII.	1·988
Difference = absorbed by hydrogen	·881
Force of combustion of ditto	1·464
Probable latent energy of gases	·583

623. This is the deduction to be made from Table XXIII. to get the working force. By similar processes we can obtain the energy absorbed in each of the different actions, and thus is formed Table XXIV.

TABLE XXIV.—ENERGY ABSORBED IN NEGATIVE REACTIONS.

		Equivolts.
Single cells:	pure hydrogen	1·464
"	liquid "	·881
Nitric acid.	Fuming	·284
"	Specific gravity 1·38	·360
"	" 1·33	·430
"	" 1·32	·479
Nitrate of soda and sulphuric acid		·708
Bichromate of potash		·343
Manganese peroxide		·687
Copper in Daniell		·506

624. By deducting the proper one of these figures from the proper one in Table XXIII., every information can be obtained as to the mode of forming batteries, and much waste of time and money may be saved in testing any idea which occurs as to a probable combination: if the requisite metal or liquid is not in the tables, the first thing to do is to make a simple experiment, and add the result to the proper table. Such a process would at once dispose of many of the crude ideas which suggest themselves to experimenters. New (so called new, that is) batteries are being continually patented still, and thousands of pounds have been lost in recent years by companies formed to work them, which would have been saved had these simple principles been understood. This, with what I have said, § 599,

is my reason for retaining so much about batteries at a time when they may be considered of small importance to most readers.

The figures in all these tables refer, of course, to the perfect condition of things, and at first starting; in all cases the changes which occur in action soon reduce the force.

625. It is evident from all these figures that E M F and chemical affinity are manifestations of one natural force. It is in fact acknowledged by all electricians that E M F is related to the potential energy of chemical affinity (even by those who say there is no interdependence though both may be related to some third agency). It is a certain fact that in electrolysis the breaking up a substance into a simpler condition, such as deoxidation, involves the presence of an E M F which takes no part in the usual formula, which is not active in producing current, that is to say, the formula must be written $E - e$ to account for the actual current produced. This $-e$ is just equal to the positive E which the reverse act of oxidation will produce. On the other hand it is known that some energy disappears which is not accounted for in the R of the circuit, and this energy again is exactly that corresponding to the chemical union broken up; here then we have the two terms, E and energy, connected and equivalent.

626. This is commonly stated in the following manner. The work done in transmitting electricity is as $E \times Q$ (which is simply $E \times C$ in another form, without reckoning time, as $C = Q \div T$), and the same formula applies to doing this against an opposing E M F, as in a decomposition cell. In this case a chemical combination is reversed, of which in most cases the calorific equivalent has been experimentally determined, as in Cols. VII. and VIII. of Table XIII.

Let H represent the heat of combination of 1 gramme of a substance; say hydrogen = 34462 combining with oxygen, and zinc passing to sulphate 1623 calories.

Let A represent the coulomb equivalent of any substance in grammes, Col. IX. Table XIII., multiplied by 10 to bring it to the C.G.S. unit; J being the equivalent of the calory in ergs, 42×10^6, and the volt being 10^8 units, we have

$$E \times Q = Q \times H A J.$$

An arithmetical result of this equation is that removing Q from both sides we have $E = H A J$, which means E M F = Energy. An example will make this plain.

In the case of hydrogen burning, we have

H = calories	34462	Log 4·5373405
A =	·00001022 × 10	$\bar{4}$·0095453
J = 4·2 × 10^7 or	42,000,000	7·6232493
Energy in ergs		8·1701351
1 volt = C.G.S. units 10^8		8·0000000
Volts of E M F due to the union of H and O		0·1701351 = 1·480

In the case of zinc, forming sulphate, we have

H = calories	1623	Log 3·2103185
A =	·00033324 × 10	$\bar{3}$·5227571
$J = \frac{4 \cdot 2 \times 10^7}{10^8}$ as before		= $\bar{1}$·6232493
		0·3563249 = 2·272

Then 2·272 − 1·480 gives ·792 as the E M F of the action of zinc dissolving and giving off hydrogen, which is much the same as the figure given § 613.

627. Hence we have this definition, *the E M F corresponding to any chemical action is equal to the product of the equivalent weight of the basic ion, and of the heat of combination of the two ions expressed as C.G.S. units of work:* that is to say, when all the elements are reduced to the absolute expression. How, in the face of such a fact and such an accepted law can any one dispute the statement that E M F is merely a metamorphosis of chemical affinity, and talk about *contact potential* in face of the evidence that both chemical affinity and E M F are forms of energy, correlative, convertible, and expressible by identical figures.

628. THE ORTHODOX CONSTANT = 46000. I mentioned in § 597 that though my conception and term, the equivolt was not welcomed by the professors and mathematical electricians, yet they made use of the thing itself. I quote this common definition "*to reduce heat units per dyad gramme molecule direct to volts, use the divisor* 46000." Dr. O. Lodge, in his admirable papers on electrolysis, gives this explanation; "If θ stands for the heat production per dyad gramme equivalent (he means molecule or atom) of the substance (e. g. per 18 grammes water, 98 grammes sulphuric acid, or 136 grammes of chloride of zinc, it is easy to see that $E = \theta \div 46000 =$ volts, for

$$J = 42 \times 10^6, \quad e\,\frac{\mu}{9660\,k}, \quad \theta = \frac{2\,\mu\,\theta}{k}$$

where μ is the molecular weight of the substance, as compared with an atom of hydrogen, and k is the atomicity or number of bonds loosed in the decomposition."

629. This is really excellent if we conceive that devisers of mathematical formulæ are actuated by the principles followed by accountants when preparing the balance-sheets of companies, to make them as unmeaning as possible to outsiders. Why should we be bothered with "dyad-gramme equivalents," and then have to insert the mystic k (atomicity) in every calculation? Why not do this once for all with modern notation chemical symbols, and get at once to the simple "monad gramme equivalent"? That is what I do in § 594 and Table XIII. Col VI., and thereby get at a *fact of nature* instead of a mere mathematical formula.

But why that very compact 46000? If any thing is certain it is that such a neat figure must certainly be incorrect: well, it is merely the result, § 532, of using that other neat round figure 42×10^6 for what would more likely requires seven figures to give correctly.

$$\frac{\mu}{k} \text{ or } \frac{H_2}{2} \text{ means } \frac{46000}{2} = 23{,}000,$$

and, using the gramme monad atom instead of the gramme dyad, 23,000 is the proper unit figure, the "constant": it is also the certainly incorrect value in round numbers for that which I give (probably incorrectly) in § 630 as 23288. As to this matter of correct values, I will quote what I wrote in the 'Electrician' about this particular subject, 27 May, 1887.

"The uncertainty of the actual value is due to the fact that we do not know exactly as yet what an ampere current is, how to get a real ohm, what we mean by a volt, the work value of the volt-ampere, or the exact mechanical equivalent of heat. We can as yet only recognize our knowledge as approximate, try to improve it, but still perceive that our errors of measurement do not affect the natural principles concerned."

630. EQUIVOLT FOR GRAMME SYSTEM.—I gave this—the constant arrived at upon these principles, which lead us to a natural law instead of a mere formula. Let H be the calories per gramme equivalent, as usually given in tables, or ascertained by H × A, § 626. Let $J = 23287{\cdot}7$, Log $4{\cdot}36712171$ being the work in calories of an ampere current effecting 1 gramme equivalent of action, in 97808·5 seconds: i.e. 6338 × 15·432.

We now have a figure which is, for the gramme equivalent and calory system, the same thing as my equivolt is for the grain-equivalent and ft.-pound system § 596. Then,

H hydrogen 1 gramme	34462	Log	4·5373405
J gramme equivolt	23287·7		4·3671271
Volts of E M F due to H and O as before			0·1702134 = 1·480

631. I have given this original value to correspond with the other values used in this Chapter, but we may as well arrive at the newer values, with ampere = silver ·001118

1 gramme H	0·0000000
Ag. ·001118/108	$\bar{5}$·0150180
Time = seconds 96601	4·9849820
Joule in ergs, Table XVII. l. 23 ..	$\bar{1}$·3797507
Equivolt 23001	= 4·3617327

This approximation to the "constant," § 628, is due to use of the erg value of the joule, which is related to the value 42×10^6.

If we use the experimental value, not to be too much trusted now the coulomb value is altered, we have

Time in seconds, 96601	4·9849820
Joule, Table XVII. l. 22	$\bar{1}$·3813859
Equivolt 23247	= 4·3663679

We shall know the true value some day.

632. WORK OF HEAT VARIES AS THE SQUARE OF THE CURRENT.—The following formulæ give the heat or work developed in any circuit, using the proper units, E in volts, R in ohms, C in amperes, T time in seconds, and J the constant representing, in Table XVII., the value of the joule of work:

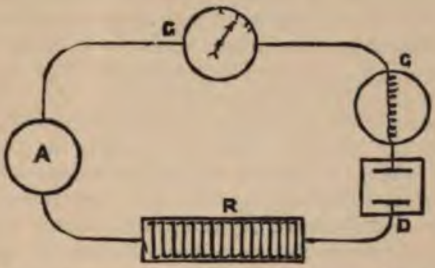
1. $C^2 \times R \times J \times T.$
2. $C \times E \times J \times T.$
3. $\dfrac{E^2 \times J \times T}{R}.$

That is to say, in the same resistance and time, the work of the current varies as the square of the current, or while by Ohm's formula, the current itself under these conditions varies directly *as the E M F*, the work varies *as the square of the E M F.*

This is a stumbling-block to many (especially when regarding electricity as a fluid) who cannot see why doubling the quantity of a fluid passing should endue it with fourfold force; but all mystery disappears when examined by the light of the molecular theory, and by aid of the hydraulic analogies, § 505, &c. Let us, then, study it in a simple experiment, employing the figures we have already obtained.

633. Let us take three similar bichromate cells, A, A^2, A^3, the force of each of which is, per Table XVIII., volts 2·028, the internal resistance taken as ohm 0·2 arranged as in Fig. 66.

FIG. 66.



G is a galvanometer whose resistance we call 0·1, and whose value in amperes is known.

R is a rheostat or resistance instrument for adjusting resistance and current as required.

C is a calorimeter, such as described § 386, the wire of which has a resistance of 1 ohm.

D is a depositing voltameter with two copper plates and a resistance of ohm 0·200.

The functions of these two should be fully understood: D measures current or "quantity," pure and simple; so long as a given current passes, exactly the same weight of copper deposits in the same time, whether 1 or 50 cells be employed, and whether the resistance of D itself be ·2 or 100 ohms. C measures the energy or heating power of the current in a fixed resistance; if this wire be 2 ohms instead of 1, it indicates double work done; but if it be 1 ohm, but the "current" be doubled, then it indicates fourfold work.

634. We wish to obtain through this circuit with one cell an ampere current, what must the resistance be? The formula is

$$\frac{E}{C} = R \frac{2\cdot028}{1} = 2\cdot028.$$

The fixed resistance is	G	·100	
	C	1·000	
	D	·200	
			1·300
A, internal resistance			·200
R, rheostat and connections; to be made =			·528
			2·028

Under these conditions a current of 1 ampere passes, and therefore in 6338 seconds 1 equivalent of chemical action takes place throughout the circuit; that is, 32·6 grains of zinc are dissolved in the cell A (independent, of course, of any local action), and in D 31·75 grains of copper are dissolved from one plate and deposited on the other, while in C heat is produced equivalent to 4673 foot-pounds of energy: that is, enough to heat 1 lb. of water a little over 6° Fahr.

635. We must now assume a few conditions to adjust the experiment to the theory. Let us consider the wire of C as consisting of a single chain of molecules, along which, during the solution of an equivalent of zinc, 4673 impulses or molecular vibrations are transmitted, each impulse being equivalent to 1 foot-pound of energy for each unit of current generated in the chain. These figures, though assumed, truly express the facts, for it is the same in the end whether one single chain represents each action as 1 foot-pound, or whether a million molecular chains transmit each only one-millionth of a foot-pound; the total figures are true either way, but the assumption furnishes a definite conception of the facts, and deals with them in simple figures.

636. Under these conditions we may deal with the E M F, and energy in a simple Dr. and Cr. account, thus:

Dr.		Equivolts.	Ft.-lbs.
1 equivalent of zinc		2,248	10,503
Cr.	Ohms.	Equivolts.	Ft.-lbs.
Absorbed in deoxidation		·220	1,028
As heat in cell:			
Struggle of polarization, *nil* ..	·000	..	..
Resistance of cell	·200	..	..
Resistance of general circuit, R, D, G	·828	1·028	4,804
Resistance of calorimeter C		1·000	4,673
		2·248	10,505

637. We now insert a second cell, A^2, and our E M F becomes 4·056, the internal resistances ·400, and therefore we reduce that of R leaving total resistance the same; then $\frac{4·056}{2·028} = 2$. Our current is now doubled—that is, G marks a current of 2 amperes per second; D deposits 63·5 grains of copper in the equivalent period of 6338 seconds, or twice as much as before; but C marks heat equivalent to 18,692 foot-pounds, or 24·2 heat units, that is, fourfold energy, instead of only double like the rest. Why? There being two units of current there are two equivalents of zinc dissolved *in each* cell. There are two cells and therefore we have fourfold energy given up by the zinc. But the chain of molecules is unaltered, except that by inserting the second cell we have doubled the strain put upon the chain, making it 4·056 volts instead of 2·028, and therefore each molecular impulse has a force now of 2 foot-pounds; owing to this double energy it overcomes the resistance in half the time, and therefore the current is doubled.

But the consequence of this is that, in the time of the experiment, we have now 4673 × 2 = 9346 molecular impulses (which represent the "quantity" or current), each effected under a force of 2 foot-pounds, and as resistance means, and is measured as, the effecting each such impulse in the single time, these conditions imply that the work of overcoming resistance in half the time is, for each ohm of resistance, 9346 × 2 = 18,692 foot-pounds.

638. We now state the second set of conditions in a Dr. and Cr. account like the first:

Dr.	Equivolts.		Ft.-lbs.
Cell A, 2 units of zinc	2·248	..	10,503
	2·248	..	10,503
Cell A^2, 2 units of zinc	4·496	..	21,006
	8·992	..	42,012

Cr.		Equivolts.	Ft.-lbs.
Deoxidation 4 units at ·220	..	·880	4,112
Absorbed per ohm:—			
In doubling current	= 2·000	..	..
In doubling force	2·000	..	..
	2 × 2 = 4·000	..	..

		Ohms.	Equivolts.	Ft.-lbs.
Resistance of cells ..	400	..	..	..
Resistance of general circuit	·628	1·028	4·112	19,216
Resistance of C ..	..	1·000	4·000	18,692
		2·028	8·992	42,020

The slight difference in the foot-pounds is owing to the use of even numbers and neglecting small fractions.

The experiment with three cells would give exactly the same result, except that 9 equivalents of energy per ohm are required to maintain a threefold current, and it is needless to occupy space in working it out in detail.

639. From all this it follows that the energy needed to generate current and the energy absorbed in the circuit or in each ohm of the resistance vary, as a fact, as the square of the current; but it is evident also that the statement that the work of a current varies in the ratio of the square of the current is, after all, only a mathematical expression based upon a single one of the two varying conditions, as with static electricity, § 86; for the real fact, as shown in the Dr. and Cr. accounts, is that it varies not as the square, but in the direct ratio of the quantity, that is, of the number of molecular actions in a given time, but that it also varies in the direct ratio of the force under which these actions occur; it is because these two necessarily vary in the same degree, one being dependent on the other, that the combined effect can be truly represented as due to the square of either one of them. The same principle will be found to underlie every action which varies in the ratio of the square of its apparent cause; examination will always discover a second cause operating *pari passu*, the two linked together and therefore producing a result which can be expressed as the square of either of them.

640. POTENTIAL *regarded as energy.* All the facts and figures in this chapter show that E M F is equivalent to *energy stored in and applied upon a definite molecular chain*; and that "volts" are as "foot-pounds" of energy thus stored.

Let us now work out the idea that E, electromotive force or potential, as expressed in the volt, represents the *potential energy stored upon and to be expended within the unit molecular chain:* the links of this chain corresponding to 1 grain equivalent of chemical action.

We have here two distinct quantities to deal with, those referred to §§ 19 and 21.

(1) A quantity of energy Q, which is 4673 foot-pounds.

(2) A *quantity so called* Q, which is treated in different manners by the different schools of electricity, and upon the clear conception of which the comprehension of electrical phenomena depends. It is commonly called the *quantity of electricity*, and is expressed by the electrostatic unit, or by the coulomb, which is 3×10^9 electrostatic units. It is also represented by the material quantity associated with the electric quantity, viz. the electric equivalents of substances.

Here it represents 6338 coulombs, the value corresponding to 1 grain equivalent of chemical action, associated under the unit system with 4673 foot-pounds of energy.

641. There is no more real mystery about these two quantities in electricity than there is in mechanics, where also they are constantly present; the mystery which surrounds them in the usual mathematical treatment is entirely due to the artificial "electricity" which has been invented by the various theorists.

We can obtain an hydraulic analogy by comparing the unit electrical conditions to those of a column of water 4673 feet in height, with such a conducting pipe as passes the unit quantity (4673 pounds of water) in 6338 seconds, which is a current of pound ·7373 per second; then the quantity and energy are expressible in terms of the pound, as a value corresponding to the unit energy of the ampere current, i.e. the joule, which is ·7373 of the foot-pound.

The same idea will probably be more completely received by many minds in the form of a pound weight suspended by a cord 4673 feet long, and doing work as it descends, in the normal time of 6338 seconds.

642. It will be well to trace the relations out step by step.

(*a*) *Electromotive force* E means a quantity Q of potential energy (of which the unit = 1 volt is 4673 foot-pounds) charged upon a chain of molecules (a quantity Q), of which each link is 1 grain eqivalent of matter.

Mechanico-motive force, § 481, will, in like manner, be represented by the column of water or the weight of § 641.

(*b*) This *potential* energy is, in the electrical case, *wholly* converted into *kinetic* energy; but the *rate of conversion* depends upon the conditions under which it takes place.

(*c*) *Rate of conversion* of energy, Q is proportional to *rate of chemical action* Q; both correspond to the rate of fall of the water or the weight § 642.

(*d*) *Current* is *quantity divided by time*, that is to say, it is rate of conversion or transmission: it is usually considered as the latter only, but it is necessary to extend the idea of the current to energy as well as matter or electricity. Therefore

$$\frac{\mathrm{Q}}{\mathrm{T}} = \mathrm{C} \quad \text{and} \quad \frac{Q}{\mathrm{T}} = C.$$

(*e*) Unit *time* is 6338 seconds, and therefore unit C = $\frac{1}{6338}$ of H, hydrogen, and unit $C = \frac{4673}{6338} = \cdot 7373$ foot-pound.

(*f*) We see that in this formula T, time, replaces R, resistance so called, in the ordinary Ohm's formula; in fact, the statement that current is quantity divided by time, and the statement (*b*) that rate of conversion or transmission depends upon the conditions under which it occurs, are the same thing differently expressed, for time is simply the inverse measure of relative facilities of conversion and transmission; if the facility of transmission is reduced to half, as by halving the area of a conductor, the time of transmission of unit quantity is doubled.

(*g*) *Time* of flow of unit quantity is therefore the measure of conducting capacity, and is the real thing represented by the so-called resistance, the R of Ohm's formulæ, which in § 441 was shown to represent the reciprocal of this capacity. In fact, current is *as conducting capacity*, and it is also (*d*) inversely as "time" or "resistance," whichever expression best suits particular requirements.

(*h*) *Electric resistance*, the R of Ohm's formulæ, represents really *the time during which the unit quantity of potential energy becomes kinetic*, and this under unit conditions of the grain equivalent is 6338 seconds: but this definition is limited to the action of unit E M F.

(*i*) The conducting capacity of any circuit is proportional to the E M F acting upon it, § 443, for this is only another way of stating the fact that current is as the E M F, or that the resistance is alike for all currents. In other words, the actual capacity = the unit × E, and it is the reciprocal of this which, § 486 constitutes the artificial "electric resistance" R, though this is arrived at by methods apparently independent of the variable E M F.

(*k*) To make the definition of (*h*) general, we must in like manner take into account the E M F operating, and then we shall find that R corresponds to T ÷ E, time divided by the E M F, as to unit energy (*i*). But R = T direct when we consider the material quantity or current; that is when C × T = Q = 1. In this case also T is really the unit time 6338 ÷ C, which in (*f*) is shown to correspond to R.

(*l*) The reason of this is evident when we consider that, as regards energy, we are dealing with limited quantities Q and *Q* divided by time T, while Ohm's formulæ deals, not with a general quantity, but only with the quantities related to a single second.

(*m*) Thus, if we double E we double current C, and therefore halve the time T during which the unit quantity Q (to which we are limiting our consideration) passes. But by doubling E we have doubled the quantity *Q* of energy connected to the material quantity Q, and therefore we have these conditions,

$$\text{As to matter} \frac{2\ \mathrm{E}}{1\ \mathrm{R}} = 2.\mathrm{C} \text{ and Q is } \frac{\mathrm{C}}{2} \times \frac{\mathrm{T}}{{\cdot}5} = 1.$$

$$\text{As to energy} \frac{2\ Q}{{\cdot}5\ \mathrm{T}} = 4.C \text{ and } Q \text{ is } \frac{C}{4} \times \frac{\mathrm{T}}{{\cdot}5} = 2.$$

These are the conditions of (*a*), those of the unit molecular chain corresponding to Q. upon which are charged quantities of energy corresponding to $Q \times \mathrm{E}$, agreeing also with the laws of energy as corresponding to $\mathrm{C}^2 \times \mathrm{R}$ or $\mathrm{C} \times \mathrm{E}$.

643. A few examples may make the matter more evident.

Action of Q = Current.	Action of *Q* = Energy.
$\frac{1\ \text{Volt}}{1\ \text{Ohm}} = 1$ Ampère. $\frac{1\ \mathrm{E}}{1\ \mathrm{R}} = 1\ \mathrm{C}.$	$\frac{\text{ft.-lb.}\ \ 4673.}{\text{seconds}\ 6338.} = {\cdot}7373$ $\frac{1\ E}{1\ \mathrm{T}} = 1C = \mathrm{J}$
$\frac{\mathrm{E}\ \ 1}{\mathrm{R}\ \ {\cdot}5} = \mathrm{C}\ 2.$ $\frac{\mathrm{J} \times \mathrm{E} \times \mathrm{C}}{\mathrm{J} \times \mathrm{C}^2 \times \mathrm{R}} = \frac{\text{ft.-lbs.}}{1{\cdot}479}$	$\frac{\mathrm{E}\ 1. = 4673.}{\mathrm{T}\ \ \ = 3169.} = 1{\cdot}479$ $\mathrm{T} = \frac{6338}{\mathrm{C}=2.}$
$\frac{\mathrm{E}.\ 2.}{\mathrm{R}\ \ {\cdot}5} = 4.$ $\mathrm{J} \times 2 \times 4 = 5{\cdot}899$	$\frac{\mathrm{E}\ 2. = 9346}{\mathrm{T}\ \ \ = 1584} = 5{\cdot}899$ $\mathrm{T} = \frac{6338}{\mathrm{C}=4}$
$\frac{\mathrm{E}.\ {\cdot}5}{\mathrm{R}\ \ 2.} = {\cdot}25$ $\mathrm{J}\times{\cdot}5\times{\cdot}25 = {\cdot}092165$	$\frac{\mathrm{E}{\cdot}5 = 2336}{\mathrm{T}\ \ \ = 25352} = {\cdot}092165$ $\mathrm{T} = \frac{6338}{{\cdot}25}$

I will work this last out fully in logarithms.

$$\begin{array}{llcr}
\mathrm{E}. & {\cdot}5 & = & \bar{1}{\cdot}6989700 \\
\mathrm{R} & 2. & = & \underline{0{\cdot}3010300} \\
\mathrm{C} & {\cdot}25 & = & \bar{1}{\cdot}3979400 \\
\mathrm{J} & {\cdot}7373 & = & \bar{1}{\cdot}8676563 \\
\mathrm{E} & {\cdot}5 & = & \underline{\bar{1}{\cdot}6989700} \\
 & & & \bar{2}{\cdot}9645663
\end{array}
\qquad
\begin{array}{rlcr}
\text{unit time} & 6338. & = & 3{\cdot}8019447 \\
\mathrm{C} & {\cdot}25 & = & \underline{\bar{1}{\cdot}3979400} \\
\mathrm{T} & 25352 & = & \underline{4{\cdot}4040047} \\
\text{unit } Q & 4673. & = & 3{\cdot}6696010 \\
\mathrm{E} & {\cdot}5 & = & \underline{\bar{1}{\cdot}6989700} \\
E & \underline{2336.} & = & 3{\cdot}3685710 \\
\mathrm{T} & 25352 & = & \underline{4{\cdot}4040047}
\end{array}$$

$$\text{Energy expended per second} = {\cdot}092165 = \underline{\bar{2}{\cdot}9645663}$$

Showing the potential energy of the E M F converted into kinetic energy in transmitting current.

644. It is obvious that all this is another mode of treating the same principles discussed in the chapter on current: the advantage of going thus fully into them is that we are brought face to face with natural processes. If in these we can clearly trace out the actual working of matter and energy we have no temptation or need for losing ourselves in imaginary abstractions when we have to deal with currents in wires, when we cannot observe the mechanism, or with E M F generated by moving an armature in a magnetic field, where also we see no visible mechanism. But in all cases we know that we are really dealing with energy and with matter capable of molecular actions; common sense tells us that the same principles are at work in the hidden mechanism as in that which we can examine. They may both be put in one circuit, and we know that the functions are similar and we need but the one explanation.

Formulæ teach nothing, explain nothing: they only apply knowledge to practice.

CHAPTER IX.

ELECTROLYSIS.

645. *Electrolysis* (breaking up by electricity) is the transmission of electric current through liquids, accompanied by disruption of the molecules composing the circuit, the constituent radicals of the molecules being set free at the two poles.

The plates in the cells are called *electrodes* (electric ways): the plate connected to the + pole of the battery, the copper or carbon, is the *anode* (way up, as carrying the current out of the battery); the plate connected to the – pole of the battery, the zinc, is the *cathode* (downward way).

The liquid undergoing decomposition is the *electrolyte.* The molecules of an electrolyte break up into two radicals, which are called *ions* (indicating individuality, and in another sense meaning *going*). Those ions which turn towards the anode are called *anions*; and those which appear at the cathode are called cations. The definition coincides with distinct chemical functions, and radicals may be conveniently classed as

ANIONS.	CATIONS.
Electro-negatives.	*Electro-positives.*
Acid radicals.	*Basylous radicals.*
Oxygen.	Hydrogen.
Chlorine.	Ammonium.
SO_4.	Metals.

646. But such a classification is only a convenient approximation, like that of conductors and non-conductors, § 25. The same ion may belong at different times to either class, according to the chemical function it fulfils in the substance and the consequent polarity assumed in the circuit. That is to say, they have *no specific attraction* to either electrode, and this fact in nature effectually disposes of the favourite hypothesis that atoms possess specific charges of + or – electricity, which are the cause of many of their properties.

647. *Ions* or radicals may be single atoms or compounds acting as radicals, and these may even be incapable of separate

existence, as far as present knowledge goes. HCl is an electrolyte composed of two atoms; in H_2SO_4 two atoms of hydrogen act as two monad ions, and the compound radical SO_4 is the equivalent dyad ion, which cannot exist uncombined, so that sulphuric acid is an electrolyte only when in presence of something it can combine with, such as water, although water itself is not an electrolyte. Ammonium NH_4 is also a compound ion, strongly resembling potassium in its properties; it also cannot exist free, but breaks up into NH_3, ammonia, and H, giving an *apparent* exception to the law of equivalence by producing two free substances, each equivalent to the current producing them, § 696; but ammonia is not really a radical, for NH_3 is a complete molecule of the order described § 13 (1), and is not capable of replacing H in salts.

648. We must now enter upon a more extended study of chemical principle and the structure of matter, and what is said here must be regarded as a continuation of the statements made §§ 4–16. But before going into this, it will be a great advantage to clear away certain theories or hypotheses which are strongly advocated by many eminent men of science. This subject is really one of pure *chemistry*, which is almost independent of the mathematical bondage to which pure *physics* are completely subject. But it has been taken up by physicists, and treated mathematically. The distinction is that the chemist is *limited to facts*, his symbols mean only real things, so that he can deal with them as *things* in safety. But the symbols of the mathematician need have no relation to truth; abstractions are even better than facts, § 330: a hypothesis or guess has the same importance as an observation: the only value of either is to serve as a wheel in the mechanism; the question of moment is, How will it work? If it works, it becomes what the casuists called a "probable doctrine," and in a little while probably an "orthodox" theory.

649. The result is that a certain set of "notions" entrammel not only our thinkers, but even our experimentalists. They start with ideas about atomic charges of + and − electricity, and then get to believing in atoms wandering about carrying these charges: they will work out elaborate calculations, prove anything they want to, show that the results agree with certain facts, and therefore are proved. Yet all this while they never touch the fundamental absurdity of the notion—that if such charges existed, and if + and − electricity attract each other, these atoms could not possibly remain free for an instant. So strong is this delusion that even so sound a thinker and so *honest* an experimentalist as Dr. O. Lodge, goes so far as to say

"in certain cases an electric current is *known* (his own italics) to consist of equal opposite streams of + and − electricity." Now neither he nor anyone else has, or can give, any evidence whatever of this, except as a deduction from *assumptions* the absurdity of which has just been shown.

650. In like manner, he and many others frequently deduce results from Clerk-Maxwell's suggestions, as a result of his theories, that dielectrics must be transparent, and conductors opaque. This is itself so contrary to known fact that it has been found necessary to extend the meaning of "transparency" to include the transmitting of any undulatory vibrations (at all events, any having the velocity of light). Now here, in electrolysis, we have a great difficulty for the theorists, as electrolytes are nearly all transparent to light, and so ought not to be conductors, while non-electrolytes are very often extremely non-transparent or opaque, and ought to conduct, if only Nature carried on her business on proper Maxwellian principles.

651. But Mr. Shelford Bidwell, who has done so much good work in examining the influence of *structures of matter*, and the relations of energy to matter, put this to the test. He tried whether "those electrolytes which transmit radiation most freely, are also the worst conductors?" He says it is "undoubtedly not the fact." I select a few examples of his results.

Solutions, &c.	Diathermancy.
Empty glass cell	1000
Distilled water	197
Zinc sulphate, sp. gr. 1·157	207
Sulphuric acid, sp. gr. 1·032	208
„ 30 per cent. 1·225	216
„ 72 „ „ 1·638	292

A glance at the Table of Resistances, § 552, will show that transmitters of undulations nearly equal—say distilled water 197 and sulp. acid 216—have conduction for electricity differing many million fold. None the less the Professors will go on using that theory as a fact.

652. THE DISSOCIATION THEORY.—This is growing in favour with the mathematical physicists: it originated in some suggestions by Williamson as to the nature of solution, and influence of the solvent on the substance; it was applied to electrolysis by Clausius, adopted by Clerk-Maxwell, worked at by Kolrausch, Arrhenius, Ostwald, and others; and Dr. Lodge appears to have a tendency to it, due to his metaphysical inclinations, and the influences noted § 649, but not yet strong enough to overcome the resistance of his common sense.

653. It is asserted on this theory, which we may call "the dance of the atoms," that substances have not the defined construction explained § 12; that dilute sulphuric acid does not consist of molecules of acid and water (H_2SO_4) and (H_2O), but that these are merely temporary formations, and their constituent atoms are perpetually interchanging among themselves like the ladies and gentlemen in the figure known as the "grand chain," or better still, like the gnats one may see on a summer evening flashing here and there and circling for a moment around each other. This strange idea was invented in order to explain why *ions* pass to the two electrodes: these are imagined to exert a force of attraction, each for its oppositely electrified ion, which during its free moments in this "dance" is gradually drawn over, § 646. A modification of the theory supposes that this condition of things is only set up by the forces exerted by the electrodes.

654. There is *not a particle of evidence to support this theory*, but there is an unlimited supply of mathematical calculations based upon such data as the (imaginary) size of molecules, the (imaginary) + and − charges of electricity upon the atoms, and the forces these might exert according to the laws of static electricity.

The specific velocity of ions has been worked out upon these data and shown to agree with certain facts of electrolysis, equally explainable by several other theories, and this sort of proof is (§ 648) thoroughly satisfactory to the mathematical mind.

But the chemical mind, trained perhaps rather too much in the opposite direction of concrete bodies, treats the combination of the atoms in a molecule as a rigid, definite union; to the chemist this molecular unity is a true marriage, rather than the promiscuous intercourse of this other theory (or at all events as a partnership for the set, to return to the "dance" analogy): he is shocked at the idea of any dissolution of the bonds of chemical affinity, except in the form of a higher affinity, a stronger force which, like death, breaks the original union only because it removes the two parties to it to new and distinct spheres. As a consequence, the dissociation theory counts few, if any, chemists among its disciples.

655. A remarkable instance of the manner in which theorists will twist facts into evidence, is given by a recent optical observation. Liquids vary greatly in their power of rotation of the plane of polarization. In most organic liquids it is proportional to the sum of that of their constituents, but this is not so with inorganic substances. The calculated value for HCl is

2·18 and in some organic solvents it was found near that: but in water it became 4·05 to 4·42, and it is said that these exceptional values are only possessed by electrolytes.

It is claimed that this proves dissociation: but it obviously gives opposing evidence: for if the H and Cl existed as such, they could only produce their normal effects, while if they exist as HCl this change of structure may well result in altered actions. The observation, if confirmed, may give us insight into the nature of electrolytes, but it will not support the dissociation notion.

656. If *free ions exist* and *carry + and − charges* which are the cause of their actions, what keeps them apart? (§ 646). But these *ions* are *atoms*, and all chemical evidence, every chemical theory, shows that *atoms never exist isolated*; they unite into molecules.

When gaseous atoms or molecules exist free in a liquid, we know as a fact that they escape from the liquid, are given off: from a solution of HCl in water, they come off, but not as H and Cl: these atoms can be dissociated, but only on condition of a supply of energy, § 585. The theorists say that they do not leave the liquid, because they cannot form molecules of the gases, as all the atoms of H are charged + and all of Cl −. But how is it that the ordinary gaseous molecules, H H, or Cl Cl exist at other times; the theory itself requires that these atoms are specifically charged H + H +, Cl − Cl −; these charges are part of their nature, they are the reasons, according to the theory itself, why they can form (H + − Cl) HCl, and really we cannot imagine that these charges and forces only exist just when they are convenient for a theory.

As a fact, dissociation does occur, under recognized conditions: if a salt containing a volatile component, say ammonia sulphate, is heated in solution, the volatile component will escape—not as *ions*, but as molecules; ammonia will be thus given off and the solution become acid: but here the required energy is supplied as in § 592.

657. The theory is *opposed to the known facts of thermo-chemistry*, fully studied in Chapter VIII. on Electromotive Force. If a body has been formed, say HCl, it lost energy in the formation, and cannot be broken up into its atoms unless that energy is supplied. The interchange of the atoms themselves cannot account for this energy *where no external force operates*; it may do so when a new force acts upon the atoms, § 698. If (H + − Cl) (H + − Cl) once exist as molecules due to the force of + − at atomic distances, what is to separate them?

658. *Velocity of ions.*—The theorists endeavour to overcome

some of the difficulties by assuming that *ions* have each a *specific velocity of motion*, similar to that recognised in the process of *diffusion* in liquids and gases. Kolrausch has calculated out these values. He gives, in centimetres per second, for certain conditions:—

Cation	H	K	NH_4	Na	Zi	Ag	$\frac{1}{2}$ Ba	$\frac{1}{2}$ Mg	$\frac{1}{2}$ Zyn
	·00300	·00057	·00055	·00035	·00025	·00046	·00033	·00029	·00025
Anion		OH	Cl	I	NO_3	ClO_3	$C_2H_3O_2$		
		·00272	·00059	·00060	·00053	·00046	·00029		

Dr. Lodge carried out some admirable experiments, which he read to the B.A. in 1884, and by the aid of "suitable hypotheses" succeeded in making them agree fairly with the figures of Kolrausch.

659. *Migration of ions.*—This really means the arrival of the separated substances at the electrodes, and what Dr. Lodge really experimented upon was the relative rates at which the presence of the two radicals was manifested in long tubes connecting the two electrode vessels. This is a real fact, but the name is itself a delusion and a snare, *the ions do not migrate at all*, § 692.

The fact is a complex one: ordinary endosmose, § 204, tends to mix the liquids; electric endosmose carries liquid *with the current*; the molecular volume of the new products differs from the original volume; the relative solubilities and associated water, § 553 are altered; but, after all, the movement experimented on, the result of all these, is the transfer, not *of ions, but of molecules*: and these contain the two opposing and combined ions.

660. *Does the solvent take part in conduction*, or is the salt the sole agent? This is one of the questions which Dr. Lodge put to his experiments, and the assumption *that water carries part of the current* was an important means of making theories and facts agree; therefore it is only just to him and important to students of his experiments, to say that at a later date he admitted that this assumption is scarcely justifiable.

Scientific honesty prohibits the idea. It is well known that pure water is almost a perfect insulator, § 706. Therefore we have no right to suppose that water, *as such*, conducts, merely because a real conductor is dissolved in it.

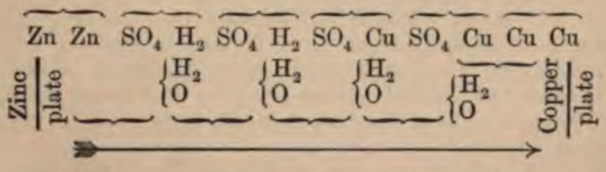
661. *The strength of a solution* modifies its conductance. We may consider that (1) this is tantamount to the sectional area of wires; a question of actual quantity of available conductor: or (2) that the salt is altered in nature by the presence of different *ratios* of water.

The bulk of liquid does not represent the conductor as in wires; nor does the old "chain" of Grotthus, generally adopted and used in this work as the "polar chain," § 465, fully account for the subsidiary *physical* effects; but it perfectly satisfies the electrical and chemical problems, and for that reason, and its clearness, will be used to explain the process of electrolysis. But an enlarged conception may be formed which does satisfy all needs.

662. *The solvent may enter* the electrolyte. It is shown § 553 that there are good reasons to believe that solution is not a mere mechanical mixture, but of the nature of chemical union, i. e. of the formation of molecules more complex than is shown by the chemical symbols employed. Now, if we adopt this view, and conceive that one or more molecules of water enter the molecule of the salt, we get an explanation which covers all the facts, electrical, chemical and physical, without having to invent any *à priori* hypothesis. We know that this does occur in crystals: we call sulphate of copper $CuSO_4$, but we know that the crystal really is ($CuSO_4,H_2O$, 4 aqua); that is, it contains 4 atoms of water of crystallization, easily driven off at a low temperature, and 1 atom of constitutional water, removable only by a considerable heat. Sulphuric acid also forms definite hydrates, thus H_2SO_4,H_2O solidifies at 8° Cent.

663. We may justly conceive that these hydrates exist in solution, and that the true electrolyte, for instance with sulphate of copper, is not $CuSO_4$, but $CuSO_4H_2O$. As we know that excess of water does travel with the copper, we may now conceive that the ions are not merely $Cu - SO_4$, but $CuH_2O - SO_4$, the water carried with the copper in a state of loose union, which breaks up at the electrode.

We may now replace the usual polar chains § 465 thus, showing the action in the liquids of a Daniell cell, as a typical case of electrolysis.



It may be thought, at first sight, that this is the same thing as saying the water carries half the current; but it is not so, because the new molecule transmits only one unit of current, defined solely by the metal set free. The water is in a sense carried over mechanically and chemically, but not electrically: electrically two ions only are affected. This idea covers the facts of *electric endosmose.*

664. WHAT IS AN ELECTROLYTE? In the first place it is a *liquid*, either by solution or fusion; some sulphides are said to undergo electrolysis while solid, but this is doubtful. It is a *liquid which conducts electricity:* as Dr. Lodge says of liquids, "if it does not conduct at all, it is a dielectric pure and simple," and dielectrics are substances which do not conduct current, but do endure *stress* or electric charge. It is not absolutely true that any solid dielectric has *no* conductance except when it breaks down. It is accepted as a natural fact that liquids cannot conduct at all unless by electrolysis; it is doubtful whether this is an absolute truth, but it is true *practically;* all apparent exceptions when fully examined become electrolytic, and therefore we may accept this as a truth. But further, electrolytes are *liquids which conduct electricity, but only when a specific E M F is applied.* But the distinguishing feature of electrolytes is that *they break up into two constituents, one of which appears at each electrode.*

A true electrolyte *consists of a pair of radicals* (ions) *which are separated by an electric current whose voltage, at the electrodes, is equivalent to the chemical affinity of the substance,* § 706.

665. *All electrolytes are also dielectrics* as regards voltages below this specific value. The decomposition cell is also a condenser.

They do not obey Ohm's law if this is left out of consideration and only the resistance of the cell is used in the formula. Fig. 58, p. 250 explains this fully: the action at the electrode consists in restoring the specific energy to the freed substances, and this means that a definite voltage is retransformed into voltance, § 599.

Dr. Lodge makes this distinction, "whereas in an electrolyte the stress is thrown upon a pair of thin films, the bulk of the medium being as quiescent and unstrained as a metal, in a dielectric the stress extends throughout the medium, sloping steadily from anode to cathode." It may be doubted whether this is the case; whether stresses exactly analogous do not exist in both cases; small in the electrolyte they may be unobservable, while they are great in the dielectric just in ratio of the voltages employed.

The "thin films" are the molecules in contact with the electrodes, and to compare the conditions we must eliminate these by allowing for the absorbed voltage, which has no parallel in the dielectric. We can render the conditions nearly similar, except that we can do so only with very low voltages, by eliminating this action at the electrodes; we do this when we electrolyse copper sulphate between copper electrodes.

666. *Electrolytes obey Ohm's law* in the circuit between the electrodes: the same formulæ relate to E, R, and C. Subject to remarks § 661, the same laws of dimensions apply as in wires.

They *develop heat on the same laws as metals*, though the effect of heat on their conductance is opposite.

They *exert magnetic actions* within themselves and around the circuit, exactly as wires do; an indiarubber or glass tube filled with an electrolyte acts precisely as a wire does.

Induced currents can be produced in such a conductor.

667. *Electrolytic conduction* is, in fact, utterly indistinguishable from metallic conduction, except for the action at the electrodes, which is not part of true conduction at all; therefore, as we are compelled to recognise molecular motions and molecular *rotations* in electrolytes, they support the idea that these are in all cases the mechanism of electric current. It may be, however, that there is this distinction, due possibly to the essential differences of solids and liquids, that while in electrolytes the real chemical molecules are the agents, in metals these may be grouped into larger aggregates which can act more mechanically than chemically. But this a mere suggestive hypothesis, and we may now return to chemical principles and facts as to the structure and functions of matter.

668. We must now conceive of substances as consisting of molecules built up of two parts, which are called *radicals* in chemistry and *ions* in Faraday's electrical nomenclature, § 645. Electrolytes are in fact, substances belonging to the molecular type, § 12, Fig. 4, and are simple binary structures.

The two radicals are held together in a twofold manner—

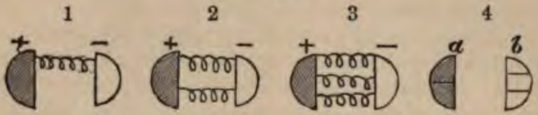
(1) By the valency of the radicals themselves, § 6. This constitutes the several classes of monobasic, bibasic acids, &c.

(2) By the specific energy of the individual substance.

Each of these has a distinct electrical relation. The first governs "quantity," and constitutes what has been called the "equivalent of electricity." The second governs the E M F generated or necessary to enable the current to pass when decomposition has to be effected, and has been fully studied in Chapter VIII.

Let us, then, typify the molecules as consisting of two parts held together by spiral springs: the *number* of the springs corresponding to the valency of the radicals, and the *strength* of the springs corresponding to the specific energy of the particular compound. We shall thus get Fig. 67, where type 1 represents the union of monad atoms, such as silver Ag. Ag., hydrochloric acid HCl, common salt NaCl. Type 2 represents metallic copper, zinc, &c., and sulphates of those metals, $CuSO_4$, $ZnSO_4$. By regarding the + radical as composed of two distinct monads § 647, as in 4*a*, it represents the sulphate of sodium Na_2SO_4, sulphuric acid H_2SO_4, and corresponding substances; or by regarding the − radical as similarly divided, it includes the chlorides and nitrates of dyad metals, as zinc chloride $ZnCl_2$. The springs, or valencies, are the bonds of § 726; they may picture the path of one unit of current, the equivalent polar chain and other conceptions, and they bring us back to the equivalent notation of chemistry § 16 (1), which accords thoroughly with the facts of electricity, while the modern atomic system, whatever its chemical merits, completely obscures them, as shown § 629, unless we clearly trace out the relations of "valency."

Fig. 67.



669. The atomic notation of chemistry is based, not only on the facts of chemical combination, but also on the relation of different substances to the forms of crystallization, and to the properties of isomeric and isomorphous bodies; and this view of the constitution of matter also covers the facts of electrolysis. It bestows upon the atoms different combining powers, as these can combine with, or replace, one or more atoms of hydrogen. This property is called the valency of the atom. But the atoms are not only capable of entering into union singly as *ions*, but two (or more) of the atoms of the same element can first unite (in which case they usually condense a portion of their combining powers) and constitute a fresh *ion* or radical, having its own proper valency. The theoretical explanation of this, known as the doctrine of "atomicity," is given in § 9, but it is unnecessary to enter into the subject of "atomicity," or to consider whether that doctrine is true or wholly imaginary, or a partial conception which may hereafter develop into a more perfect theory by aid of the revelations of the spectroscope. What we have to do with is *the fact* that the several weights called under this new system the *atomic* weights, do represent in combination chemically, one, two, three, or more atoms of hydrogen. Again, it is a fact that molecules do exist which, in the gaseous state,

contain the elements in these ratios by volume; thus HCl hydrochloric acid, H_2O water, H_3N ammonia, each contain these relative volumes of H for one volume of the other gas: when combined they, every one of them, occupy two volumes, the same volume, that is, as the molecule of hydrogen HH, and these molecular volumes hold, all alike, the same relation to energy, for they expand equally for equal heats and pressures, at all events within the range of usual experience.*

670. Therefore *Valency* is the *gaseous volume combining ratio* of hydrogen, or of other elements, to the unit volume of hydrogen, but extended by indirect calculations to those elements whose gaseous volume cannot be directly measured. The *atomic* weight is the weight of a unit volume of the elements in the gaseous condition, compared to that of hydrogen as unity.

671. *This does not imply* of necessity that *these atoms are the ultimate elements of the structure* of matter, even if they actually exist, and are not merely the convenient creation of chemists: there is no conceivable objection to regarding them as "concretions" composed of so many equivalents of their component element as they possess valencies, for it is certain these equivalents exist and have their definite function. Going beyond this, there is nothing to limit us in imagining that even these elementary equivalents are complex bodies; but these imaginings carry us into the field of metaphysics, and have no place in real scientific investigation.

672. As modern science accepts the doctrine that heat is a "mode of motion," and as motion implies space to move in, it is obvious that there must be a relation between heat and the space occupied by the moving particles; heat being only one form of energy, we readily extend this relation to energy in all its forms, and therefore, we can see that there is in nature an exact relation among the weights of the atoms of matter, the spaces they move in, and the energy they absorb, that is to say between the atomic weights, molecular volumes, and intrinsic energies of substances. We can see that if, by the agency of energy, atoms are made to occupy a different space from that common to them, they must have new properties; that is to say, under altered conditions of energy, the *valency* (which is a function of volume and energy) will be altered; as a consequence we can conceive of the existence of two or several compound substances containing the same elements and in exactly the

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* There is reason to doubt whether the accepted laws of Petit, Dulong, Marriott and Avogadro are absolutely true over great ranges of temperature. All this justifies the belief that these "atomic weights" do represent some real fact in the structure of matter, and in chemical relations.

same proportions, but, owing to differences of intrinsic energy, having very different chemical properties, and belonging to entirely different molecular types. This may explain "isomerism" (equal measures of the same elements in different compounds), "allotropy" (different forms of the same substance), as due to different specific energies, and also probably a different number of atoms entering into the molecules, which have consequently different physical properties. Carbon, sulphur, and phosphorus are well-known substances taking different forms, and ozone O_3 is a modified molecule of oxygen, containing three atoms of O instead of two, condensed to the normal twofold molecular volume.

673. Berzelius's electro-chemical theory which long ruled chemistry, assumed that each element possessed, as part of its constitution, a definite quantity of positive or negative electricity, which set up the chemical attractions between them, that they united into acid and basic radicals, the attractions of which for each other were due to the excess of + or − electricity not neutralized in the primary act of combination. This theory implies that different substances possess *different quantities of electricity*, which are the causes of the varying degrees of affinity: it differs in this respect from the similar modern theory, §§ 649, 656, and this classification of electro-positives and negatives with their degrees of charge resembles rather the gradation of specific energy, § 585. Hemholtz, however, adopts the idea that each atom has its specific attraction for electricity.

674. But Faraday distinctly proved that there is a relation based upon the equivalent constitution of matter. Thus, if a cell is set up, based upon zinc displacing silver from its nitrate, a definite quantitative result will be effected by the current; if passed into a copper solution, it will reduce a definite quantity of copper, in the ratio of the old equivalents of the metals. But copper will precipitate silver, though with less force than zinc does; if, then, copper is used with a silver salt, a current will be set up, and this current also will, for the 108 grains of silver in the battery, deposit 31·75 of copper in the cell. Again, iron will thrown down the copper, and zinc the iron; in each case a lower affinity at work in the battery produces exactly equal reduction in the cell, though taking a longer time to effect it. But, again, if we place in a series, cells containing different classes of molecules, and pass a current through all—such as salts of silver, copper, and iron—the same current passes through them, and deposits in each cell its metal in the order of its equivalent. Therefore Faraday said that every molecule,

no matter what the chemical affinity within it, requires or gives up the *same quantity of electricity*, and this is Law IV., § 683.

675. How shall we reconcile these two conflicting views, for both of them are based on truths? Careful consideration of the facts will show us that Berzelius based his ideas upon the conditions set up by "intrinsic energy," while Faraday's law is based upon the "valency" of atoms and radicals, and consequently upon the construction of molecules.

When we see that electricity is connected to the molecular constitution of matter, that it can be transmitted or measured *only by motions of the molecules* transmitted along a definite chain by the action of one molecule upon another, we see that there must be a relation to the *number* of molecules moved or broken up, which relation we may call a *quantity* or an *equivalent* of electricity, and so take possession of Faraday's labours.

When we learn that energy is an integral part of the molecules of matter; that the component atoms are moving at definite rates, as the spectroscope shows, and that chemical combination effects a reduction of that motion, and its release as external heat, or as motion along a line of polarized molecules in electricity, we see why each such action must give up a definite amount of energy, and why, according to its amount, the molecular motion it sets up (the "quantity") shall be slow or rapid, and the stress set up great or small in the ratio of the chemical affinities at work. Here, then, we take possession of Berzelius's labours, and connect the two conflicting theories into a more general conception, which is the one worked out in these pages, the molecular theory of electricity.

676. We can now give to Faraday's "quantity," or "equivalent of electricity," a definite value accordant with the chemical constitution of matter and modern chemical views, viz.:—

$$\frac{\text{Atomic weight}}{\text{Valency}} = \text{electric equivalent.}$$

It is that action which releases one univalent radical, elementary or compound; that is to say, it passes along one of the links by which molecules are constituted, as represented in Fig. 67, § 668; it also exerts a definite magnetic effect by its inductive action upon the structure of surrounding substances. This unit of electricity, measured on a grain system, is that used in this work, viz. the equivalent of one grain of hydrogen. Each molecule of the modern system, therefore, acts in the electric circuit as though it were so many real molecules as represent the "valency" of the two radicals or ions into which it breaks up. How or why this relation exists our present knowledge does not enable us to explain, but that this is the true relation of electricity to matter is certain, for this law covers all the known facts, all the exceptions to the common accepted laws of electrolysis (§ 683); but we can see that it is probably connected with the unit atomic gaseous relation of matter and energy, extended into all other physical conditions.

677. But electrolytes have another relation to electricity besides that of current equivalent. An electrolyte, setting free its two radicals, requires a definite force exerted upon it, variable, not by classes, but with every substance according to the strength of the chemical affinity of the two ions.

If we set up a battery and a certain resistance, a given current will pass; extra resistance will diminish the current, but no amount of resistance will quite stop it: but an electrolyte will do so, and a current which can traverse one electrolyte will be wholly stopped by another.

If we use an E M F which will just pass current through iodide of potassium, and then substitute for this dilute sulphuric acid, no electrolytic current will pass at all; the decomposition cell is not a mere resistance, but a *counter electromotive force.*

This only illustrates the fundamental law of Nature that action and reaction are equal. If we pull on a rope fixed to a post, the post resists us, and the strain on the rope at the post exactly equals that at the other end; spring balances at the two points would show the same pull in opposite directions. So, when chemical affinity is exerted in combination, it sets up an E M F in one direction, a stress on the polar chain; if decomposition occurs, the radicals set free absorb an equivalent energy, and act as an E M F in the opposite polar direction, that is, as a − E M F. Therefore it is that to effect decomposition against any chemical affinity, the E M F exerted must be somewhat greater than the − E M F set up, or no action can occur at all; upon the degree of excess will depend the rate of action. To ascertain, therefore, the amount of electrolysis which can be effected by any battery, and under any conditions of resistance, the formula is $\frac{E - e}{R} = C$.

678. Turning now to the examination of the facts of electrolysis, we must regard the whole circuit as composed of chains of molecules; some metallic as in the plates and wires, some liquid as in the cells; we recognize that the transmission of electricity is effected by a motion in these molecular chains accompanied by a breaking in halves of a molecule in each cell, of which one half or ion appears at each pole; one molecule being

really broken up at each electrode, but the remaining halves uniting through the chain to form a molecule; the molecules themselves and the ions being all equivalent in value, however much they differ in properties.

679. Each cell is, therefore, a section of the conductor, and has its own specific resistance, just as the wire portion has. But the cells are of two orders in another respect.

(1) Generating cells, in which energy is set free by chemical actions, and becomes E M F, as explained §§ 594–621; these are battery cells and stand for E in formulæ.

(2) Decomposition cells, in which energy is absorbed in doing chemical work. These may be simple resistances, where no ultimate change is made in the solution; such are most electro-metallurgical processes where the same metal is dissolved from the anode as is set free at the cathode. But if any *ions* are actually set free by the current, they tend to recombine and act as a cell of the first order with their E M F opposed to that of the battery, and stand as $-e$ in formulæ. The feeblest E M F will send a current through the first of these classes of decomposition cells, but the second class require an E M F greater than that set up by the action itself, or electrolysis cannot occur, § 677.

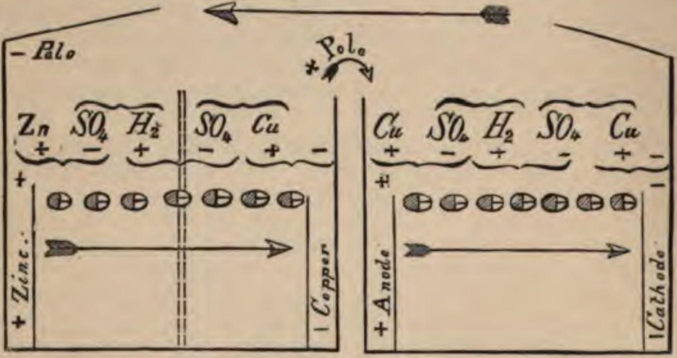
680. Except for this distinction of generating and decomposing cells, all the cells are under the same conditions. In each cell there is a + plate or element, the zinc in the battery cells and the anode in the decomposition cells, and if the latter can unite to the chlorous radical of the electrolyte it dissolves just as the zinc does in the battery cells. In each cell there is the electrolyte, which gives up its chlorous or − ion at the + plate and transmits the molecular motion which constitutes the current to the − plate, where it also gives up its + ion. The − plate then continues as the + pole or anode to the next cell, and ultimately to the − pole or terminal zinc of the battery to complete the circuit. In fact, each pair of connecting plates in separate cells acts as though it were a metallic partition separating the two liquids with which the plates are in contact. In such a conducting partition, one side would be + and the other side −, and the two plates in different cells correspond to these two sides, united by a wire instead of by the mass of a plate. It is of the utmost importance to bear in mind this distinction of *plates* or *elements*, related to the liquid within their own cell; and *poles* or *electrodes*, related to another cell and to the polarity they set up, or transmit, and the student should carefully study the diagram of these actions § 293.

681. Leaving out of sight the distinction of cells as those

setting up and those absorbing energy, that plate in each cell which is + to its own liquid, or the positive *plate* of the cell, is the anode or + electrode of the cell to which it is connected, and completes the circuit from the – plate of this cell. Hence it is that the anode in the decomposition cell represents the zinc in the battery cell, for like the zinc it is + to the liquid, and gives up energy to the liquid (though that energy is derived from the current itself in this cell), and like the zinc it dissolves, if made of materials which can combine with the negative or – radical of the solution. For this reason some prefer to call the anode the *zincode.*

682. Fig. 68 exhibits these relations, in the actions of a Daniell cell and an ordinary coppering arrangement.

Fig. 68.



Battery. *Decomposition.*

It shows the polarization set up in the complete circuit from the zinc in the liquid, with equivalent actions resulting in both cells, the upper brackets showing the original arrangement of liquids, the lower ones the effect of the action. At the + plates to the left in each cell, zinc in the battery, the anode in the decomposition cell, an atom of metal is removed from the plate; the intervening molecules transmit the action, and absorb the ion originally united to the first acid radical; and in each cell, at the end of the chain in contact with the negative plate or cathode, there is set free a positive radical; in this case copper in both cells. This diagram is arranged to furnish several illustrations of the laws of electrolysis, and should be studied in connection with Fig. 67, § 668, which more fully explains the ideas to be associated with the ellipses in Fig. 68; these represent the molecules and their constituent radicals or ions, expressed also in the chemical formulæ, while the symbols + and − show the classes of radicals, + being the cations, and − the anions; their arrangement exhibits the order of polarity set up, while the arrows show the direction of the current within the cells and in the outer circuit.

683. The *laws of electrolysis* usually accepted are those of Faraday, who originated the terms used. These laws are—

I. *No elementary substance can be an electrolyte.*—That is to say, the two ions must be differently composed.

II. *Electrolysis occurs only while the body is in the liquid state.*—This state may be due to either fusion or solution; in the latter case many substances become electrolytes by a *secondary* action, which are not so of themselves.

III. *During electrolysis the components of the electrolyte are resolved into two groups; one group takes a definite direction towards one of the electrodes, the other group takes a course towards the other electrode.*—They turn towards the several electrodes in polar order, but are not moved towards them by a direct attraction of the electrodes. Faraday held that only substances containing single equivalents of each radical are electrolytes, but this is now superseded by more general conceptions, § 672.

IV. *The amount as well as the direction of electrolysis is definite and is dependent upon the degree of action in the battery, being directly proportional to the quantity of electricity in circulation.*—This law is explained by § 676, which shows that "quantity of electricity" means number of equivalent molecular actions.

V. *Those bodies only are electrolytes which are composed of a conductor and a non-conductor.*—This addition of Miller's is useful to remember, but scarcely ranks as a law of nature.

684. General Law of Electrolysis.—*At the electrodes those substances are set free which absorb, in becoming free, the least intrinsic energy, or lowest voltance.*

That is to say, at the point where the current enters or leaves the electrolyte, any neighbouring molecule, *whether an electrolyte or not*, will be ranged *in the polar circuit*, provided, that (1) one part of it can unite with the true *ion* turned towards the electrode, and the other part can form a free molecule, absorbing less energy than the *ion* of the true electrolyte would require to become free; or that (2) the true ion can be introduced into this other molecule at a less expense of energy than it would need to constitute a free molecule. The substances set free may be thus formed afresh out of materials in contact at the electrodes, not merely separated as ions or radicals from previously existing molecules, although this latter is the fundamental type and general action of electrolysis.

685. But if the voltage at the electrodes exceeds this required voltance, then the substance needing the next least energy will also be set free, in proportions dependent partly on the voltage, partly on the density of current, and partly upon the relative proportions of material present at the electrode.

686. This conception, first published in this work, shows an analogy between the effects of electricity in electrolysis, and those of heat in destructive distillation. As in this last case the substances arrange themselves in new forms suited to the forces existing in the retorts as degrees of temperature, so in the decomposition cell they arrange themselves in forms suited to the forces existing as degrees of electric stress.

687. Since this law was first published, M. Berthelot has formulated a general law of chemistry, which he calls the *principle of maximum work*, § 585; that is to say, when substances act on each other, that action occurs which sets free most heat; this principle underlies all the actions treated of in the chapter on Electromotive Force, and it is evident that M. Berthelot's law of maximum work is the converse of the general law of electrolysis which I have formulated.

688. *The quantity of electrolytic work* effected by a current according to § 676, may be calculated thus:—E and e (§ 677) being expressed in volts, and R being the total resistance or ohmage, metallic and liquid, C will be the current in amperes; this multiplied by time in seconds, and ·000010352, the coulomb equivalent, gives the work effected in terms of the "electric equivalent" § 676, and this again multiplied by the value in Col. VI Table XIII. or as calculated, gives the weight in grammes of the substance: or this same figure may be used in place of the ·000010352. See also § 724.

This may be put into a formula: if v is the electric equivalent of the substance set free, k a constant representing the hydrogen value of the ampere current, that is, for grains 0·0001598, for grammes 0·000010352, and equivalent figures for ounces, pounds, &c., E volts, R ohms, t time in seconds, and W the quantity, or work done,

$$W = \frac{k\,v\,E\,t}{R} \qquad (E = E - e)$$

689. Counter E M F.—This, which is the source of the E M F of secondary batteries, has been explained §§ 622 and 677:

whether we regard the decomposition cell as a condenser in which a stress is produced, or as a place where chemical decomposition occurs under superior force, each action tends to make the anode + and therefore to oppose the current.

The battery and decomposition cell are, therefore, identical in principle with two cells with similar poles opposed, and no current can pass unless the electromotive force of the one cell (the battery) exceeds that of the other cell (the electrolyte).

690. It is generally believed that this − E M F is not set up when plates of metal are electrodes in a solution of the same metal, as in coppering. This is not correct. It is evident that the plates cannot be in the *same* solution, because the action itself produces concentration at the anode and impoverishment at the cathode. I have found that this generates a small − E M F and that the copper deposited in a decomposition cell worked by a Daniell cell is never quite equal in quantity to the copper deposited in the battery if worked with a wire having equal resistance to the decomposition cell. I find this − E M F about ·02 of a volt.

691. But M. Lossier has shown that there is another source of − E M F; that the mechanical energy absorbed in the action produces this as it does in magnetizing: he states that "a current traversing any electrolyte develops a − E M F equal to the square root of the current and the resistance": that is $e = \sqrt{C r}$. This therefore varies with the current, being of the nature of work § 525, and is in addition to the chemical reaction, which does not vary with current. There may also be a − E M F caused by the different molecular condition of the metals, as rolled, cast, or deposited, as these varied conditions alter the E generated in dissolving.

692. The electrodes of a cell are not necessarily metals. When the liquids are separated by a porous diaphragm, their surfaces in contact act as electrodes to each other, and precipitation may occur there just as at a plate. A series of liquids may be thus connected, and current passed through the whole. The examination of this will clear away many common misconceptions. Thus it is often said that "ions can be transmitted through materials for which they have a strong chemical affinity without combining with them." Now this is not the case. No ion can be so transmitted. The illustration usually employed represents three connected liquids—sulphate of soda, infusion of litmus, and water. After a time sulphuric acid is found in the water, and it is considered that it has passed through the litmus solution, yet has not coloured it. But what has occurred is quite different. Not sulphuric acid, but neutral sulphate of

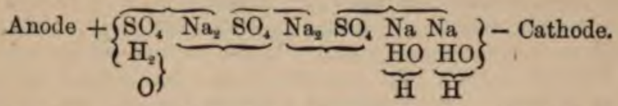
soda, has traversed the solution, by simple endosmose. Until this has brought some of the salt over, no acid would be released, nor would any current pass at all unless some saline substances were in the water.

693. But if in any intermediate solution there is a chemical affinity for one of the ions, capable of producing a precipitate, that ion will never pass across the solution. Suppose there are four solutions, common salt at the cathode, sulphate of soda next, then nitrate of silver, and again sulphate of soda—no particle of chlorine would ever find its way to the anode, but sulphuric acid would be set free there; any chlorine which either by endosmose or by electrolytic transfer reached the silver cell would be at once precipitated there. What really occurs is interchange of the ions between contiguous molecules along the polar chain, so that when this is composed of different electrolytes in contact, the constituent ions are soon distributed; but whenever in the course of this distribution two ions come together which have a mutual affinity great enough to cause an ordinary chemical combination, they become insoluble, and drop out of the polar chain. Faraday proved this by decomposing sulphate of magnesia in contact with water in strata one above the other, and with precautions to prevent disturbance by gas: no magnesium found its way to the cathode, but on entering the water it formed a film of magnesia in the middle of the liquids at the line of junction, which served as electrodes to the liquids. This bears strongly on the "migrations of ions," § 659.

694. To understand the chemical actions effected by the current, we should examine them first in a pure electrolyte, a single substance: and most of those have to be liquefied by fusion. A good example is chloride of silver with silver electrodes: the silver adheres to the cathode and the anode dissolves away, maintaining the chloride of silver constant. This is *Direct* Electrolysis. With a large number of substances in *solution*, a different action occurs, which is called *Secondary* Electrolysis. I will give the usual explanation of this first, and then show a principle which explains it more perfectly and in better accord with the principles of the electric current.

695. If we electrolyze a solution of sodium chloride NaCl, we obtain Cl at the anode; at the cathode we do not obtain Na, but we have instead of it H, hydrogen, in the equivalent proportion: in the solution we have an equivalent also of caustic soda NaHO. But if we electrolyze sodium sulphate Na_2SO_4, we obtain at the anode an equivalent of oxygen O, and also an equivalent of free sulphuric acid H_2SO_4, while at the cathode we have the same

as in the case of the chloride; we have, therefore, apparently two equivalents set free for one equivalent of current. The explanation given is this: if we add sodium Na to water, we decompose the water, we produce NaHO caustic soda, and H as free hydrogen. When we decompose NaCl, we really set free Na in presence of water, which is then decomposed by *secondary* or purely chemical action. In the case of the sulphate we also set free at the anode (or render nascent) SO_4 a radical which cannot exist separately, but which acts upon water, H_2O, forms H_2SO_4, and sets free O oxygen, also by a secondary chemical action. We may picture the reaction thus:



$$\text{Anode} + \left\{\begin{array}{lllll} SO_4 & \overbrace{\underbrace{Na_2\ SO_4}} & \overbrace{\underbrace{Na_2\ SO_4}} & Na & Na \\ \left.\begin{array}{l} H_2 \\ O \end{array}\right\} & & & \underbrace{HO}_{H} & \underbrace{HO}_{H} \end{array}\right\} - \text{Cathode.}$$

The upper row of brackets show the original molecules of Na_2SO_4, of which the end ones break up and react upon the water, which does not enter the polar electric chain.

696. It should be noted that we have here, as in § 647, an apparent production of two equivalents for one equivalent of electricity, as we have at the anode an equivalent of free acid generated, and also O set free; and at the cathode we have free caustic soda and H as gas. If this explanation were true, the E M F required would be that of composition of Na_2SO_4, and that is by Tables, p. 308, NaO, 14593 foot lbs. and $NaO + SO_3$ 3137: or $17732 \div 4673 = 3 \cdot 8$ volts. There would also be heat produced in the liquid equal to that of the action of sodium on water. Now we know that an E M F of 1·5 volts is sufficient to just set up the action, and that this heat is not generated. To understand what really occurs, and so get rid of the complication of direct and secondary electrolysis, we must distinguish between the actions in the *body of the liquid*, and those which occur *at the electrodes*, § 550.

697. *The action in the body of the liquid* consists of molecular motions transmitting the current, and the interchange of ions among themselves as they happen to meet with others capable of combining with them. These actions are entirely of the nature of *resistance* (except as explained § 691): the current, therefore, will divide itself among any number of mixed electrolytes as among different wires, in the order of their conductance; therefore, in an ordinary coppering solution containing a good deal of free acid, the current will be carried mainly by the acid, because the conductivity of sulphuric acid 1 to 11 of water is 16 times as great as that of sulphate of copper solution.

698. *The breaking up of the molecules involves no expenditure of energy* in this case, as it did in § 657, because here there is an external force operating through the polar chain; it does break up the terminal molecules, expending *energy in that action*: but the mere interchange of ions throughout the chain, without disruption, needs no energy, because the energy imparted to the remaining ions at the ends of the chain enables them to unite through the chain itself, which transmits the stress and the energy; any energy which may really be consumed in the process is therefore of the order of resistance or friction, and finally appears as the heat of R, see § 705 (3).

699. *At the electrodes there is a selective power.* This is not based on resistance, but solely upon the ratios of voltage required to free the several ions. If several anions are in contact with the anode, that one will be set free whose intrinsic energy is lowest; hence in dilute hydrochloric acid, &c., chlorine is selected because its energy with hydrogen is only 4721 foot-pounds, while the other anion present, oxygen, requires 6841 foot-pounds. If the anode is soluble, that anion would be selected whose energy of combination is highest, because here the action is really that of a generating cell and (§ 705) contributes energy to the polar circuit as + E M F (both these statements are subject to limits which will be considered presently). At the cathode a similar selective action occurs: thus, if a copper solution contains iron, copper only will be reduced, because the − E M F of copper is only 1·26 volt, while that of iron is 2·07; for this reason hydrogen is not released in presence of metallic salts, except when their specific energy, or − E M F, approaches nearly to that of hydrogen, or under a great excess of E M F. Hence in depositing nickel or iron, hydrogen is always given off, despite of Smee's law to the contrary. The principles I am laying down show us why. The − E M F of iron is 2·07, and that of hydrogen is only 1·9, nearly the same.

700. It is possible that in some cases a true *secondary* or *chemical* reaction occurs. Such are those actions in which no direct *ion* is released from a broken-up molecule; but a complete molecule has a part of its constituents removed or substituted, or extra atoms (forming the true ion released) are added to it. Such an action occurs at the cathode with nitric acid: the *nascent* hydrogen reacts upon it in manners varying with the rate of current and the concentration of the acid; if this is weak, hydrogen is given off. The different reactions which occur are given, § 228.

701. A corresponding action may occur at the anode with

nascent oxygen or chlorine. On this account it is dangerous to electrolyze a strong solution of sal ammoniac, NH_4Cl, and I select this example because it is an experiment very likely to be made; it decomposes into ammonium NH_4, which breaks up into NH_4+H at the cathode, and Cl at the anode; chlorine reacts upon the salt and forms drops of chloride of nitrogen, a violent unmanageable explosive: thus $NH_4Cl + 6Cl = 4HCl + NCl_3$. I give this formula for simplicity sake, but no one knows what chloride of nitrogen is.

But while these actions, producible by ordinary chemical reactions, may be regarded as secondary actions of substances set free, it is more probable that the molecules reacting are actually ranged in the polar electric circuit, and that the actions are effected under the influences exerted by the current. We may therefore substitute for the confusing ideas of direct and secondary action the general conception, § 684, that the products of electrolysis are ranged according to their ratios of specific energies.

702. MIXED ELECTROLYTES.—When several paths are open to the current, it divides itself among them all in the inverse ratios of their several resistances. Every conductor is, in fact, a system of such "derived circuits," as the unit conductor is the single chain of univalent molecules. It is shown, § 554, that in liquids all parts form a system of derived circuits, of unequal resistance, from every part of one electrode to every part of the other, and as a consequence every portion of the liquid in the cell carries a part of the current proportioned to the lines of resistance in which it enters; but this relates only to the true conduction, § 697. The conditions are quite different when the different "derived circuits" are different electrolytes; those conditions will also be very different when the electrolytes are in different cells, and when they are mixed in one vessel.

703. The travel of the current (*conduction*) is inversely as the resistances, and probably independent of chemical exchanges: the entrance and exit of the current (*electrolysis*) is inversely as the voltances, and each is probably independent of the other. There is no reason to believe that there is any symmetry in the process, which confines it throughout to one substance.

The current will act on no substance, § 619 (at the electrodes, it may in the circuit) whose – E M F exceeds the potential to which the electrodes can be raised, as shown on an electrometer connected to the two electrodes; yet it may do so apparently. It may at one electrode select one ion alone, and at the other an ion either originally forming part of the same, or of a different electrolyte; or it may release several and redistribute the other constituents. It will release, first, at each electrode, ***such ions as take up least energy***, whether they originally formed part of the same electrolyte or not. If the potential is raised much beyond the point needed for this, ions requiring more energy will be released, in ratios dependent largely upon the quantities present, and in contact with the electrodes, § 685.

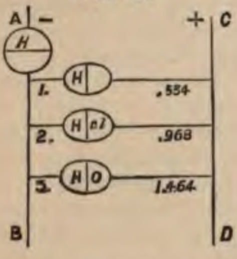
704. ELECTROLYTES IN DERIVED CIRCUITS.—If, instead of going through a mixture of several electrolytes, the circuit is divided into several branches, or derived circuits, with a decomposition cell in each branch, containing electrolytes of different − E M F, then a different set of conditions will arise. The experiment is highly instructive and very simple: U tubes serve as cells, or straight tubes turned up at the ends, of such length and size, as enable the resistance to be made nearly equal: a galvanometer of very simple type, should be used in each circuit, or one will suffice, if a resistance equal to the galvanometer is provided for each circuit, so that the galvanometer can be inserted in place of it without altering the conditions of current.

The result will be according to the laws of derived circuits, § 528, modified by the different opposing E M F's. Let Fig. 69 represent three such derived circuits, containing

1. Sulphuric acid with a copper anode, with − E M F = ·534
2. Hydrochloric acid with platinum electrodes .. .. " = ·968
3. Sulphuric acid with platinum electrodes " = 1·464

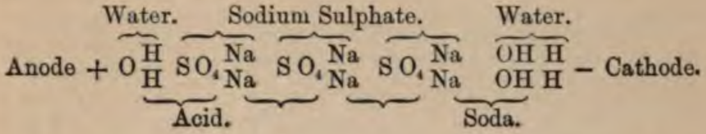
The common current being measured by a voltameter or Smee cell § 198, A will give as much hydrogen as 1, 2, and 3 together; but the ratios between these latter will be quite another matter. Until the potential between A B and C D rises to ·534, no current would pass; then it would go wholly by 1; when it rose beyond ·968 a little would go by 2, but only a small proportion; and it would require greater battery power than if 2 were acted upon alone, because by the laws of derived circuits, the E M F would be equal at all the junctions of 1, 2, 3, with A B, and, therefore, the facility of passage opened through 1 would rapidly lower the potential in the common conductors, and make it more difficult to raise it to the degree necessary to pass any current through 2 than it would be were 1 disconnected.

FIG. 69.



705. Electrolytic Reactions.—We may now apply these theoretical principles to well-known reactions.

(1) The decomposition of sodium sulphate, instead of taking place by "secondary" action, as shown in § 696, is effected by molecules of water entering the polar chain itself: the extreme ions of the chain go off as gases, and the formula becomes,



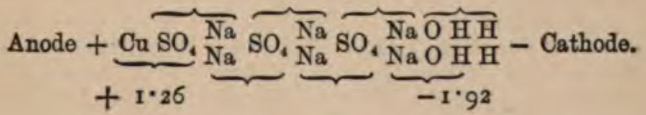
$$\text{Anode} + \overbrace{O\begin{smallmatrix}H\\H\end{smallmatrix}}^{\text{Water.}}\ \overbrace{SO_4\begin{smallmatrix}Na\\Na\end{smallmatrix}\ SO_4\begin{smallmatrix}Na\\Na\end{smallmatrix}\ SO_4\begin{smallmatrix}Na\\Na\end{smallmatrix}}^{\text{Sodium Sulphate.}}\ \overbrace{\begin{smallmatrix}OH&H\\OH&H\end{smallmatrix}}^{\text{Water.}} - \text{Cathode.}$$

$$O\underbrace{\begin{smallmatrix}H\\H\end{smallmatrix}\ SO_4}_{\text{Acid.}}\ \underbrace{\begin{smallmatrix}Na\\Na\end{smallmatrix}\ SO_4}\ \underbrace{\begin{smallmatrix}Na\\Na\end{smallmatrix}\ SO_4}\ \underbrace{\begin{smallmatrix}Na\\Na\end{smallmatrix}\ \begin{smallmatrix}OH\\OH\end{smallmatrix}}_{\text{Soda.}}\ \begin{smallmatrix}H\\H\end{smallmatrix}$$

The upper brackets show the original molecules, and the lower ones the result of the action; and I have individualized the atoms in order to show why a bibasic salt, such as a sulphate, takes two equivalents of current to decompose it, the equivalent being based on H, § 676. The student should compare this diagram with that in § 696, and thoroughly realize the difference of principles involved in them.

This reaction requires 1·5 equivolts—that is, so much energy must be given up by the current, to set oxygen and hydrogen free, and the cell will act as a $-e$ of that strength.

(2) But the anode represents the zinc of a battery cell, § 680, and if it can combine with any anion or acid radical present it dissolves like the zinc, and gives + energy to the circuit. If therefore the anode is made of copper, current would pass with less expenditure, and the action would become



$$\text{Anode} + \underbrace{Cu\,\overbrace{SO_4}}_{+\,1\cdot26}\overbrace{\begin{smallmatrix}Na\\Na\end{smallmatrix}}\ \overbrace{SO_4\begin{smallmatrix}Na\\Na\end{smallmatrix}}\ \overbrace{SO_4\begin{smallmatrix}Na\\Na\end{smallmatrix}}\ \overbrace{\begin{smallmatrix}O&H&H\\O&H&H\end{smallmatrix}} - \text{Cathode.}$$

$$\underbrace{\begin{smallmatrix}Na\\Na\end{smallmatrix}\ SO_4}\ \underbrace{\begin{smallmatrix}Na\\Na\end{smallmatrix}\ SO_4}\ \underbrace{\begin{smallmatrix}Na\\Na\end{smallmatrix}\begin{smallmatrix}O&H\\O&H\end{smallmatrix}}_{-1\cdot92}$$

Here we see that the energy absorbed is 1·92 − 1·26, or only 0·66 of an equivolt, because at the anode a reaction occurs which gives up energy; or, more simply, there is only absorption at the cathode for setting hydrogen free, in excess of that due to copper solution: if zinc were used in place of copper, still less energy would be absorbed.

(3) We may have at the cathode also, an ion which needs no more energy than a corresponding reverse action at the anode will supply, then we have an electrolysis which is only a resistance, not a $-E$, § 679 (2) and § 698: and therefore the very

feeblest force can effect it. If we place copper sulphate at the cathode of the last reaction, it becomes

$$\text{Anode} + \underbrace{\text{Cu}\,\text{SO}_4}_{+1\cdot26}\,\overbrace{\genfrac{}{}{0pt}{}{\text{Na}}{\text{Na}}\,\text{SO}_4}\,\overbrace{\genfrac{}{}{0pt}{}{\text{Na}}{\text{Na}}\,\text{SO}_4}\,\underbrace{\genfrac{}{}{0pt}{}{\text{Na}}{\text{Na}}\,\text{SO}_4\,\text{Cu}}_{-1\cdot26} - \text{Cathode.}$$

This is an ordinary coppering reaction, in which, to keep up the analogy, I have used soda sulphate in the circuit, instead of copper sulphate or sulphuric acid as usual. The copper, in combining with the acid, gives up 1·26 equivolts, as + E M F, and the final decomposition absorbs the same as − E M F, leaving only the resistance of the cell to overcome.

(4) In the ordinary voltameter with dilute acid we have a reaction which it will be seen resembles the decomposition of sodium sulphate (1), but the hydrogen comes off at the cathode without producing any other substance there, because the acid itself supplies the hydrogen.

$$\text{Anode} + \underbrace{\overbrace{\text{OH}_2}\,\overbrace{\text{SO}_4\,\text{H}_2}\,\overbrace{\text{SO}_4\,\text{H}_2}}_{\text{E M F} - 1\cdot464} - \text{Cathode,}$$

giving besides the resistance of the cell, a — E M F of volt 1·464; so that a single Daniell of volt 1·079 cannot pass current at all; but if we use as in (2) a copper anode, giving a + E M F ·93, so reducing the − E M F to ·534, current passes freely, hydrogen is given off, and sulphate of copper formed. In formula (2) this reaction shows a force of 0·66, while here it is ·534, although in both cases the same products are set free; but the presence of the caustic soda in the first case introduces an element which does not exist in the other, and this is the cause of the greater force required. All these figures are given, however, to illustrate principles, not as actually accurate in themselves.

706. WATER NOT AN ELECTROLYTE.—Almost all the books speak of the decomposition of water; in fact, they commonly attribute the processes of electro-metallurgy to secondary action of the hydrogen set free by the decomposition of water; they speak also of water being a bad conductor, but made better by the presence of acids and salts. The foregoing principles enable us to define *a true electrolyte as a pair of ions which will break up under a potential equivalent to the affinity which holds them together*, § 664. It is doubtful whether pure water is not one of the strongest insulators; at all events, it will not only not electrolyze

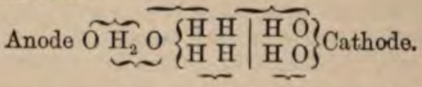
under a potential of 1·5 volt, but resists a hundred times that E M F: therefore it is not an electrolyte.

707. This point has been often argued. Some have said that alternating currents will decompose water, only the constituents reunite at the electrodes, § 556; this plan is obviously merely reversing the charges of a condenser, swinging the water molecules backwards and forwards, not breaking them up, nor passing current through the water at all. Others have tried to diminish the resistance by coiling up two platinum plates separated by silk, giving great area and little thickness of liquid. They passed current, and got gases unquestionably, but it is scarcely necessary to say that it was not pure *water* which was being decomposed. The fact is, really pure water is unknown, even to chemists; it cannot be made, and, if made, could not be kept five minutes. Water is a close approach to the long-sought object of the old alchemists—a universal solvent. The purest platinum, even though made red hot, &c., is sure to have *some* residuary impurities or adherent gas, and thus the conditions of ideal electrolysis are inevitably vitiated.

708. If the anode be silver, after a time traces of silver are found in the water, and from this it has been argued that water is an electrolyte, but that its very great resistance prevents measurable current passing. The argument is not valid: when the water is polarized as a dielectric under stress, its oxygen of course will unite with the silver, which, passing into solution, constitutes an electrolyte.

709. Water and many other substances permit a slight current to pass without undergoing electrolysis; and it has been argued that this is caused by the gases being given off and absorbed by the liquid. We cannot limit nature, nor can we be quite sure that liquids cannot conduct, in some degree, like metals and solids, as even gutta-percha does. But there is another point to consider. Water freely dissolves air, and takes up the oxygen in a higher ratio than the nitrogen: it is by this property that fishes are enabled to breathe; therefore, when, under the influence of the charge, the water, acting as a dielectric presents its hydrogen to the cathode, it finds there oxygen with which it can combine, while the corresponding oxygen is set free at the anode, with the result of a small current passing; this action is therefore perfectly analogous to the transmission of current across a copper solution between copper electrodes, in fact oxygen is transferred instead of copper. Helmholtz has proved this by means of a carefully prepared hermetically sealed "gas free cell"; he found that this slight current diminished as the gas was got rid of, and finally, was altogether put a stop to.

710. In the reactions called the decomposition of water, the gases do not come off pure, and consequently the theoretical measures are rarely obtained. Ozone is generated at the anode, and peroxide of hydrogen at the cathode. These are remarkable substances, possessing the contradictory properties of being both oxidizing and reducing agents. Ozone is a molecule of oxygen containing three atoms instead of two, and with the third atom ready to leave at the earliest opportunity; therefore it will take oxygen from an oxidizing agent to form ordinary oxygen, and hydrogen from a reducing agent to form water. The reaction may be written thus:



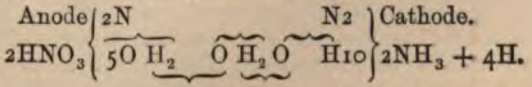
$$\text{Anode}\ \overbrace{\text{O}\ \text{H}_2}\,\underbrace{\text{H}_2\ \text{O}}\ \left\{\begin{matrix}\text{H}\ \text{H}\\ \underbrace{\text{H}\ \text{H}}\end{matrix}\right.\ \Big|\ \left.\begin{matrix}\text{H}\ \text{O}\\ \underbrace{\text{H}\ \text{O}}\end{matrix}\right\}\text{Cathode.}$$

An atom of oxygen released at the anode, and its two atoms of hydrogen acting on two molecules of water, so as to form two molecules of free hydrogen and one of hydrogen peroxide H_2O_2 Three such reactions give three atoms of oxygen to form a molecule of ozone O_3 at the anode.

711. Mr. G. H. Robertson has shown, a few days before this part of the work went to the printers, that this generation of H_2O_2 plays a very important part, hitherto overlooked, in the chemistry of secondary batteries, § 310, its presence being the cause of the high E M F just after charging, § 324, about 2·5 volts; he proved this by an experimental cell, the plates of which could be exchanged in the liquids, which caused an immediate fall of voltage.

712. *Small electrodes* facilitate these exceptional actions owing to two causes: 1, increased *density of current*, so that the molecules of H_2O in contact with the electrode are more tumultuously solicited by the nascent O, or in other words the usual influence of relative quantities come into action, § 716; 2, the resistance being greater, the stress on the molecules is greater, as the potential is higher.

713. Water containing air, when electrolyzed by a powerful current, generates nitric acid HNO_3 at the anode, the nascent oxygen uniting with nitrogen and water, and ammonia at the cathode by union of nitrogen and hydrogen, thus:

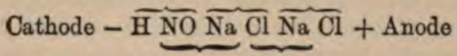


$$\begin{matrix}\text{Anode}\\ 2\text{HNO}_3\end{matrix}\left\{\begin{matrix}2\text{N} & & & \text{N}_2\\ \overbrace{5\text{O}\ \underbrace{\text{H}_2\quad \text{O}}} & \underbrace{\text{H}_2\ \text{O}} & & \text{H}10\end{matrix}\right\}\begin{matrix}\text{Cathode.}\\ 2\text{NH}_3 + 4\text{H}.\end{matrix}$$

714. Dissociation.—When current from a machine enters water by means of fine points, decomposition occurs; it is

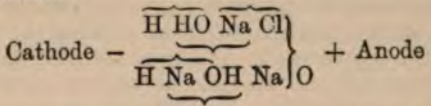
not, however, *electrolysis*, but *dissociation*; both gases are given off together at each of the electrodes; this is due to the high tensions set up and the violence of the vibrations produced, analogous to the action of a flash of lightning, so that the atoms of O and H constituting water are, as it were, shaken apart. Similar dissociation is produced chemically in water (as steam), and in many substances when the temperature or heat tension rises beyond the degree at which combination occurs. This fact has a striking analogy to the disruptive action exerted in electrolysis when the potential rises beyond the chemical affinities of the radicals, but it has nothing to do with the hypothetical dissociation of § 652.

715. In the electrolysis of common salt NaCl, for every unit of currrent one atom of hydrogen will be released at the anode throughout the action; but none of the other reactions will be uniform: at first the action accords with the ordinary laws, and for each atom of hydrogen there will be an equivalent of sodium hydrate at the cathode, and of chlorine at the anode.



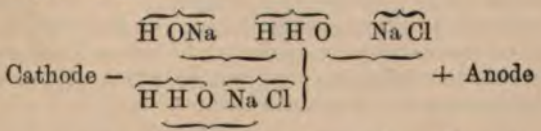
$$\text{Cathode} - \overbrace{\mathrm{H\ NO}}\ \overbrace{\mathrm{Na\ Cl}}\ \overbrace{\mathrm{Na\ Cl}} + \text{Anode}$$

But, as the caustic soda accumulates, it carries a part of the current, and then commences a series of complicated actions at the anode. Chlorine is no longer given off alone, but some oxygen accompanies it by part of the chorine regenerating sodium chloride thus:



$$\text{Cathode} - \left.\begin{matrix}\overbrace{\mathrm{H\ HO}}\ \overbrace{\mathrm{Na\ Cl}} \\ \overbrace{\mathrm{H\ Na}}\ \mathrm{OH\ Na}\end{matrix}\right\}\mathrm{O} + \text{Anode}$$

716. The same reaction also extends itself by taking up a molecule of the salt, and forming sodium hypochlorite, instead of setting the oxygen free.



$$\text{Cathode} - \left.\begin{matrix}\overbrace{\mathrm{H\ ONa}}\quad\overbrace{\mathrm{H\ H\ O}} \\ \overbrace{\mathrm{H\ H\ O}}\ \overbrace{\mathrm{Na\ Cl}}\end{matrix}\right\}\ \overbrace{\mathrm{Na\ Cl}} + \text{Anode}$$

In consequence of this and similar reactions, chlorates and other oxygen salts may be formed at the anode when chlorides are electrolyzed, instead of the full equivalent of chlorine being given off. In the electrolysis of hydrochloric acid, similar results occur, and oxygen is set free as well as chlorine, and the ratio of oxygen increases as the acid is weaker, because there are more oxygen atoms in the vicinity of the electrode.

717. These reactions, and apparatus for carrying them out, have been often patented for bleaching purposes, and will no doubt be profitably utilized for that and other purposes now that electrolysis can be cheaply effected by the dynamo and steam engine.

718. These various examples have been selected because of their special significance. They are commonly treated as slight exceptions from the established laws of electrolysis, or results of "secondary" action. They really show that this indirect, chemical, or secondary action is a delusion; dismissing it, we can ascend to that higher law formulated § 684, with all its theoretical and practical results.

719. In electrolysis there is *no direct transfer of ions* from one electrode to the other, but a constant interchange of radicals in contact, which, owing to the selective power exerted at the electrodes, tends to the accumulation of two classes of radicals, which in the case of salts in solution would ultimately collect all the acids on one side and all the bases on the other, as described § 721; but this could never be effected by a current equivalent only to these products, because a continual reversion of the action and diffusion of the products goes on; in practice, also, in a depositing cell long-sustained action transfers the metal of the anode to cathode. But the anions or chlorous radicals tend to accumulate most rapidly, and this has important results in electro-metallurgy, because they act on the anode and surround it with a saturated solution; while the removal of the metal at the cathode tends to produce a weak and acid solution there, just where a dense metallic solution is most desirable; in fact, if we use a neutral solution of copper sulphate in a cell with a porous partition, and drive a strong current through, in a little while the anode will be covered with crystals of sulphate of copper, formed there but unable to dissolve, while the solution at the cathode will be so exhausted as to give the metal mixed with hydrogen.

720. The mode of transmission of ions, and the way in which the metal of the anode is transferred to the cathode, may be represented in the following diagram, in which copper is supposed to be immersed in sulphuric acid:

$$\begin{array}{ccc} & 1.\ \overset{+}{\mathrm{Cu}}\ \overbrace{\mathrm{SO_4H_2}}\ \overbrace{\mathrm{SO_4H_2}}\ \overbrace{\mathrm{SO_4H_2}} & \\ \text{Anode} & 2.\ \mathrm{Cu\ SO_4Cu\ SO_4H_2\ SO_4H_2} & \text{Cathode.} \\ + & 3.\ \mathrm{Cu\ SO_4Cu\ SO_4Cu\ SO_4H_2} & - \\ & 4.\ \underbrace{\mathrm{Cu\ SO_4}}\underbrace{\mathrm{Cu\ SO_4}}\underbrace{\mathrm{Cu\ SO_4}}\mathrm{Cu} & \end{array}$$

The lines show successive actions which involve a redistribution of the radicals, and the newly-formed molecules make a semi-revolution so as to renew the polar condition; at each action, therefore, a molecule of copper sulphate is formed by copper entering at the + end, and hydrogen leaving at the cathode § 705 (3), until at length copper sulphate reaches the cathode, and copper can be set free there instead of hydrogen. The student should compare this explanation with that referred to in § 652. But while he avoids the error of attributing the action to some mythical attraction exerted by the single electrodes on oppositely electrified ions, and clearly realizes that it is a molecular action between the electrodes and the liquid in contact, he must not overlook the other condition which also exists. The electrolyte is really occupied by a "field of force," such as exists in static charges, and all its molecules are therefore under the static or di-electric stress which plays its part in the action.

721. EXPERIMENTS in electrolysis are very interesting and instructive, and every one who wishes to understand the subject should make them for himself, taking care as far as possible to watch all the quantitative relations of the current by some of the means described in the chapter on measurement. There have been many complicated forms of apparatus devised, but the most important experiments can be performed by the simplest means. Wires of suitable metals serve for electrodes, and small U tubes made by bending up pieces of glass tubing will serve for cells, the two liquids being placed separately in the legs; in some cases it may be well to fill the bend with fine sand; straight lengths of tube, closed at the bottom with a plug of plaster of Paris or asbestos, may be used by dipping them in a vessel of suitable connecting liquid. When gases are to be collected, test-tubes can be used, filled with the liquid, closed with the finger or with a piece of sheet indiarubber, and inverted over the wire electrode. The instrument described § 578 is also suited to electrolytic experiments.

722. By connecting several such cells or U tubes in series, the student will see that the acids all collect in one arm, and the bases in the other; and by using them singly and noticing the E M F or number of cells needed to pass any given current, he will make clear to himself the relations of the force and observe the reacting force set up, while the conditions of Fig. 69 can be studied by mounting the tubes side by side in multiple arc. For instance, let four U tubes contain—1. Solution of potassium iodide with a little starch; 2. Common salt, coloured blue with sulphate of indigo; 3. Ammonium sulphate with

infusion of cabbage; 4. Copper sulphate. Connected with platinum wires and placed in series with a strong battery, the anode arms will show acid reactions; 1 will be coloured blue by freed iodine; 2 will be bleached by chlorine; 3 will redden by sulphuric acid; 4 will show acid on litmus paper. The cathode arms will show the presence of the bases; 1 will turn turmeric paper brown by potash; 2 will do the same by soda; 3 will become green by ammonia, or blue if litmus is used in place of cabbage; 4 will deposit copper. Used singly or in multiple arc with increasing power, they will show the forces needed for each reaction.

723. Oxides are thrown down in a solid form from some salts. Such are the nitrates and acetates of lead, manganese, and bismuth, from which the peroxides as PbO_2 MnO_2 are deposited upon the anode. With the lead salts very beautiful effects are produced, as the peroxide in different thicknesses has different colours through which the metal may partially appear. By acting on a polished plate from a pointed electrode, rainbow-tinted rings are formed on the principle of Newton's rings, due to the interference of the waves of light reflected through the film, which diminishes in thickness as its distance from the point increases.

724. This process is capable of practical application by way of ornamenting metallic surfaces; some attempts in this way have been made, and it offers a promising field.

Many practical uses of electrolysis may be discovered. It offers a cheap and convenient mode of producing any chemical effects which depend upon *oxidation* or *deoxidation* according to the electrode used. It has many applications in chemical analysis. Hydrogen peroxide, § 711, is largely used as a hair wash to give a golden colour (best left undone). It is used to purify sewage, more or less profitably. It does in hours the work of years in ageing wine and spirits, and kills fermentation. A very large sum of money was also extracted from the British public by an ingenious American who professed to refine sugar, and Prof. Silvanus Thompson deserves credit for having denounced that pretence before it was shown to be a deliberate fraud. In the production of dyes it would seem that electrolysis would be a most convenient agency.

725. THE WORK OF ELECTROLYSIS.—The formula given § 688 is adapted to scientific and experimental purposes, but the ampere is too small a measure, and expressions corresponding to actual operations would be found more convenient. The ampere hour is commonly used, but has disadvantages, and decimal *multiples* of the unit of quantity, such as "meg-coulomb,"

though admirable to the minds of Professors, are not likely to please any one else. The weights used in practice are the best units of quantity, and I have calculated the following table. To convert these figures into actual substances, multiply the one selected by the "electric equivalent, Table XIII. col., 6 or as calculated, of the required substance."

Weights.	1 Coulomb.		3600 Coulombs.	
	1 Ampere-second.	Logarithm.	1 Ampere-hour.	Logarithm.
Gramme	·000010352	−5·0150180	·037267	−2·5713205
Grain	·000159753	−4·2034497	·575112	−1·7597522
Ounce, Troy	·000000333	−7·5222085	·001198	−3·0785110
Ounce, Avoirdupois	·000000365	−7·5624717	·001315	−3·1187742
Pound ,,	·000000023	−8·3583517	·000082	−5·9146542

726. Let k represent (as in § 688) *the one of these selected* and v the electric equivalent of any substance, then

$$k \times v = \text{W or quantity of the substance.}$$

$$\frac{\text{W}}{k \times v} = \text{Q or} \begin{cases} \text{electricity required in the} \\ \quad \text{corresponding unit.} \end{cases}$$

$$\text{Then } \frac{\text{Q}}{\text{Time}} = \text{Current, and } \frac{\text{Q}}{\text{Current}} = \text{Time required.}$$

727. For practical operations it would be advisable to translate the scientific terms and values into corresponding special terms; that is, instead of reckoning currents in amperes to measure them directly in terms of the special work: this is, in fact, using an enlarged "chemic" unit; thus an electrotyper would measure his current in terms of ounces of copper per hour or pounds per day, and an electro-plater in the ounces of silver corresponding to them. Then galvanometers could be graduated in those units, as I have long done, and with one controlling each operation, the workman would understand what was going on, and guess-work would be converted into exact knowledge.

CHAPTER X.

ELECTRO-METALLURGY.

728. Although electro-metallurgy is a purely practical art, and its successful practice may be accomplished with a very small modicum of science, this is true only of the factory; to learn it from books and solitary practice, and in any case to learn it intelligently and to pass beyond the range of mere "rule of thumb," it is necessary to clearly understand the principles in operation, and the terms necessarily employed in explaining those principles; and reference will be made, where required, to the earlier pages in which these may be found. For this reason, also, if any one hopes to learn at once how to rival Elkington in the art of electro-plating, or even, having got a Smee cell and half a pint of gilding solution, to at once proceed to gild his watch-case or chain, he may as well resign himself to disappointment; he must go through an apprenticeship by first learning thoroughly how to deposit copper in any required condition; this is a cheap and manageable process, and all the secrets of electro-metallurgy can be learnt there, and, once mastered, success in the other departments is assured, and only slight instructions are necessary for each special case.

729. The first thing essential to be considered is the source of the current and energy. On the large scale that would nowadays certainly be the dynamo-machine, and if expected readers were mainly intent on business considerations it might be well to begin with describing the various kinds of machines obtainable. But addressing rather experimentalists, students, and general readers, who may often be quite out of reach of anything but what they can provide for themselves, I prefer to meet their requirements. But the principles are the same for all modes of working, and all that I have to say will be equally applicable to working from machines as from batteries, on the manufacturing scale, as in tumblers. The general principles, and particulars as to the source employed, will be found in the chapters relating to them.

730. The basis of all knowledge is experiment, and the very

essence of experiment is exactness; and this latter can be obtained only by regular measurements, a matter rarely attended to in electro-metallurgy. It is impossible to urge too strongly alike upon the learner and the practical operator, the advantage of keeping in the circuit a suitable galvanometer, which will always show whether operations are going on properly, call attention to any irregularity, and measure at every instant the actual work doing, while showing the effect of any variation in the conditions. In this way the work itself soon teaches its laws. For most purposes in metallurgy a vertical instrument is best, as explained § 364. For experimental purposes, however, the instrument § 361 is expressly adapted, and galvanometers to show current in amperes are now easily obtainable.

731. The principles and processes of electro-metallurgy may be classified and studied under several distinct heads, and sound knowledge can be obtained most readily by carefully distinguishing these heads. The mere process of removing the several metals from their solutions is a part of the general theory of electrolysis, of which it is a practical application; that theory therefore should be carefully studied in Chapter IX., so that we may secure the metal in such conditions of cohesion, colour, &c., as we desire.

732. There are two distinct objects sought.

(1) To form a fresh object in metal which is to have a separate existence of its own, and must, therefore, possess a certain substance and strength; this is called electrotyping, as forming of copper plates, solid vessels, duplicates of coins, medals, &c., and divides itself into the two cases of deposits on metals, and on non-metallic models, the formation of which has to be undertaken.

(2) The newly formed metal adheres to that on which it is placed, and which it beautifies, or protects from atmospheric and other influences. This is called *electro-plating*.

733. This classification would appear to be the really important one, but this is not the case; for the result is simply a detail of the first head in the next classification to be considered.

(1) The preparing of the object to be deposited upon, including moulding, cleaning, &c.

(2) The actual deposition; selection and making of the required solutions, and regulating the electrical energy for the due performance of the required work.

(3) The finishing off the completed work.

The first and last of these are in the main mechanical operations, and may be considered together.

734. THE PREPARATION OF THE OBJECTS.—The first question is: Do we require an adherent deposit, a superficial plating; or do we wish a removable coating, an electrotype? The first can only be obtained upon a metallic surface, and that a metal not acted upon by the solution to be used; thus it is in vain that we may try to get a coating of copper on an object of zinc or iron in a solution of sulphate of copper. This comes under the second head, however.

735. To obtain an *adherent deposit* there is one essential—cleanliness. And this means the perfection of that virtue, not such cleanness merely as will satisfy a scullery-maid, or even her mistress, as to the plates and dishes, but chemical cleanness, the absolute absence of any foreign matter whatever, as such matter, however clean to ordinary ideas, is *dirt*, as Lord Palmerston defined it, matter in the wrong place. Thus, a piece of silver or gold taken off a shelf, however bright and clean it may look, would not take an adherent coat if put into a coppering or silvering cell and deposited upon; on burnishing it probably, on heating it certainly, the coating would blister and strip. The reason is that every substance has a film of air closely attached to it, and the deposited metal forms on this film and not in molecular contact with the metallic surface; thus, in the case considered, the air, however pure it may be, is dirt—i. e. it is in the wrong place, between two surfaces we want to be themselves in absolute molecular contact.

736. If a surface has been cleaned to perfection, and it be touched with a dry finger, on that spot the deposit will be non-adherent, and in many cases, if cleaned by liquid processes, even a momentary exposure to air will cause the formation of a film of oxide, &c., which, infinitesimal and even undiscoverable as it may be, will still prevent adherence; so that it is of extreme importance to understand what is meant by chemically clean, and how to secure that condition, if it is desired to avoid the most mortifying disappointments.

737. If we desire a *non-adherent* removable deposit, we require ordinary cleanliness, the removal of extraneous dirt, but we must avoid absolute cleanness, § 750.

738. Articles may be cleaned either by dry or wet processes, the first consists mainly of brushing with the aid of polishing materials—fine silver sand, emery, tripoli, whiting and rouge—according to the nature of the article. It should be observed here that whatever condition we desire in the finished article we must produce in the object before commencing deposition: bright parts should be burnished, and all roughness of workmanship smoothed off, and all file marks and scratches carefully

removed. But for adherent coatings absolute finished polish is not desirable, and while it is proper to burnish the required parts so as to give a close finish, yet before actual deposition this burnish should be slightly removed, as perfect adherence is less easy to obtain on an absolutely smooth surface; an instant's dipping in strong acid is enough to give the burnished surface the capacity of adherence without deteriorating from the beauty of finish.

739. There is reason to suppose that the deposit is not merely a cohesion of two distinct surfaces, but that the deposited metal penetrates to some depth within the surface and forms a partial alloy or chemical union: the hard burnished surface would tend to resist this, while the open granulated surface left by the acid would facilitate the union.

740. The best cleaning and polishing apparatus is in the form of circular brushes mounted upon a lathe; in factories this is always employed in the form of the scratch-brush lathe, a rough affair driven by steam or by a common treadle, with fittings to supply a constant drip of various liquids found to facilitate the action, such as soap and water, stale ale, &c. Amateurs who have no lathe employ common hand brushes of bristles of various degrees of stiffness; for the harder work of cleaning, the wire "card" is very useful; and for the more delicate work scratch-brushes are employed, in the form of bundles of very fine wire bound round with stronger wire which is unrolled as the wires wear down. The same sort of brushes are employed in finishing off the articles after deposition. These matters being purely mechanical and self-obvious to any one after a little practice, it is not necessary to go further into detail about them. For the rougher work emery has now come into much use: a disc of wood fitted to run in a lathe, its edge provided with a leather surface to which emery is attached by good thin glue, does as well as expensive discs, and a still more useful arrangement is a long strip of leather, like a driving band, coated in a similar manner, and driven at a high speed. Polishing brushes are also made of strips of calico, &c., attached to a disc and run at such a speed that the so-called centrifugal force makes the flying ends act very effectively.

741. Many metallic substances it is advantageous to heat and plunge into acids; but this must not be done with objects which are soldered, or whose temper or hardness it is necessary to preserve. As a rule, the first thing to be done (where this heating is inapplicable) is to remove the greasy films which most objects acquire either in use or course of manufacture: this is effected by boiling and rubbing in a solution of caustic soda, made by

boiling about 2 lbs. of common soda crystals with milk of lime, produced by slaking ½ lb. of quicklime with hot water and well stirring; this will produce a gallon of suitable solution, from which it is not necessary to remove the carbonate of lime formed, as it will assist in the cleaning. The boiling must be effected in an iron pot, not tinned, as tin would be dissolved and deposited upon objects afterwards. After this alkaline bath the objects should be well washed in several waters or under a running stream. They are next cleaned in acids, and again very carefully washed before passing into the depositing vessel; but this stage requires a classified consideration based on the several metals of which they are composed.

Silver may be washed in dilute nitric acid, then dipped in strong nitric acid for an instant and washed. It will require no further treatment. There must be no hydrochloric acid or chlorine salts present.

742. *Copper, brass, and German-silver* are immersed in a pickle composed of water, 100 parts; oil of vitriol, 100 parts; nitric acid, specific gravity 1·3, 50 parts; hydrochloric acid, 2 parts.

The nitric acid is of the strength sold as double aquafortis. An acid prepared for the purpose is sold as "dipping acid." Two vessels should be employed for this acid; one fresh, for a final dip of an instant or two, and one partly spent, in which the principal cleaning is effected. If there are green spots of verdigris on the object, these should first be removed by rubbing with hydrochloric acid.

743. For coppering, this cleaning would be enough; but for silvering and gilding, it is better to coat the surface with a thin film of mercury. Dissolve 1 oz. of mercury in nitric acid with 3 parts of water, and dilute to 1 gallon; a grey coating will form on the objects dipped in this, which, on brushing softly, gives place to a brilliant coating of mercury; the object should be transferred to the depositing cell the instant this is obtained, otherwise it soon tarnishes, and will require fresh preparation. There should be a little free nitric acid in this mercury solution, and whenever there forms a black deposit somewhat adhering, the mercury is becoming exhausted. Solder, lead edges, &c., give much trouble, as it is very hard to prevent a black line forming at the junction, which prevents silver taking; the remedy is to first coat them with copper; to a soft brush (camel's-hair pencil), tie one or two thin iron wires, so bent that the points closely follow that of the brush, which is to be dipped in a weak solution of nitrate of copper, prepared by dissolving the metal in weak nitric acid; draw the wet brush over the solder, the iron touching it; a reaction is set up, which

causes the copper to be deposited in a thin adherent film, on which the electric deposit will fix itself.

744. *Britannia metal, pewter, tin, and lead* should not be dipped in the acid pickle, but rinsed in a fresh caustic soda or potash solution, and transferred at once (without passing into water) into the solution for silvering. The reason is that the oxides of tin and lead are soluble in caustic alkalies, while the products of the action of acids are not soluble in water.

745. *Iron and steel* are soaked in a solution of 1 lb. of oil of vitriol in a gallon of water, with a little hydrochloric and nitric acids added. Cast iron requires somewhat stronger solutions and very careful rubbing with sand, &c. Steel, on the other hand, requires weaker solutions. They may often be effectually and speedily cleaned by treating them as anodes in this solution, using a plate of copper as a cathode.

746. *Zinc* may be treated similarly, but it is desirable to finish with a dip into stronger acids before the final washing. Most of the French "bronzes" are made of zinc, and some do well for silvering on. In these last cases no copper or other metals should be dipped in the baths, and soldered joints must be treated as described above.

These latter classes require special preparations and treatment in the depositing baths, but the same classification applies there, and the details will be given when treating of the depositing processes themselves.

747. Preparing Old Work.—In replating old goods it is essential that the former silver, &c., should be removed, otherwise a black line forms at the junctions, and sound deposit cannot be obtained. In factories, this is usually effected mechanically by the scratch-brush, with the aid of oil and rottenstone, and the debris are collected and reduced to recover the metals. The metals may also be removed chemically.

(1) *To remove Gold.*—Immerse in strong nitric acid, and add crystals of common salt: when the acid is exhausted, evaporate to dryness, and fuse with soda or potash to obtain the gold.

(2) *To remove Silver.*—Immerse in undiluted oil of vitriol, add crystals of nitrate of potash (saltpetre), and heat. This may be done in a copper vessel. When spent, dilute largely, and throw down the silver with scraps of zinc, or as chloride, by adding hydrochloric acid. The silver may be recovered from this by fusing with carbonate of soda, or by mixing with zinc cuttings and sulphuric acid. This process can be used with copper, German-silver, or even brass, but not iron, lead, or its alloys; these should be placed as anodes in a silvering solution which will not attack the lower metals.

(3) *To remove Copper* from silver, boil with dilute hydrochloric acid.

(4) *To remove Tin and Lead.*—A hot solution of perchloride of iron (jeweller's rouge, or the druggists' carbonate of iron dissolved in hydrochloric acid) will dissolve copper, tin, or lead without attacking silver or gold.

748. VESSELS.—For all the foregoing processes, no better vessels can be had than the best hard brown earthenware; for small articles, a kind of basket is made of this material, with handle for dipping and shaking about. The same material is available for the plating liquids themselves, though glass is preferable for small operations. For washing, it is well to arrange a succession of vessels with spouts, or slightly inclined, at such a level below each other that a stream of water will flow from the highest to the lowest, so that by rapidly passing the object from the lowest upwards, it is perfectly cleaned; for amateurs, the simplest plan is to hold them under a water tap, and remove them in a pan of water straight to the next stage.

749. CONNECTIONS.—All objects must be securely connected electrically with copper wires. Where it is possible these should be soldered, but usually the connection has to be one of mere contact: for large objects, several wires should be provided; for small ones, such as spoons or forks, little stirrups of No. 30 or 32 wire are best, fixed to a stouter wire, and the points of contact with the object should be frequently shifted, otherwise it will be defaced by a mark when finished. For this reason, the wire actually in contact with the object should always be as small as possible, though it may be fixed to a stouter wire at a short distance. These connections should be fixed under water, and with the hands scrupulously clean. It is an advantage to pass the wires through a small glass tube reaching above the level of the liquid, so as to check deposit upon the wire itself. For connecting non-metallic objects, see § 764.

750. REMOVABLE DEPOSITS.—ELECTROTYPES.—The objects on which these are to be formed should be made simply clean by the removal of loose dirt; if metallic, they should then be lightly rubbed over with a tuft of cotton-wool moistened with turpentine, with a piece of beeswax the size of a pea dissolved to the quarter pint; this, when dry, will not interfere with the deposit, but will prevent adhesion. The back and all parts not intended to be deposited on should be covered with varnish or wax for acid solutions, or treated as described, § 765.

751. MOULDS.—Many objects have to be deposited, not on the originals themselves but upon copies or moulds made from them,

and some judgement is necessary in selecting the best materials for the purpose: we have to consider (1) what the material of the original object is, and (2) the material which will work best with this, and also suit the process of deposition to be used; we must not use a material which might injure the original, or be acted on by the solutions, this latter being the case with all resins, wax, and stearine in cyanide solutions. We should regard first the objects to be moulded from, the processes being considered inthe order of their advantage.

(1) *Metallic objects, coins and medals, &c.*, are moulded from in fusible metal, guttapercha and marine glue, plaster of Paris, or composition; the surface should generally be rubbed with sweet oil to prevent adhesion; or if it is not objectionable, they may be well polished with plumbago.

(2) *Plaster casts* may be moulded from in plaster, in which case they must be rendered perfect non-absorbent by the means described § 754; they may also be copied in composition, in which case they must not be so prepared, or the object and mould will adhere, but must be so saturated with water that the surface is moist but not wet, at which stage the composition can be poured on.

(3) *Wax or sulphur* may be moulded from in plaster.

752. Fusible Metal or Clichee.—This material has the advantage of requiring no preparation to render it conducting, and is connected by simply pressing a heated tinned wire on any suitable spot, and protecting by varnish the parts not to be deposited on. The principal objection to its use is the dearness of bismuth, to which the ready fusibility is due. The mixtures most available are:

	Lead.	Tin.	Antimony.	Bismuth.	Fuse at
(1)	5	3	0	8	212°
(2)	5	4	1	8	..
(3)	1	1	Cadmium·	2	200°
(4)	4	2	1·5	7·5	151°

The metals are melted and added in the order shown, stirred well together, and granulated by pouring gently into water. The alloy should be melted and granulated two or three times to insure complete mixture. The value of these bismuth alloys arises from their assuming a pasty condition before setting, and expanding in cooling, thus taking a very sharp impression. A small paper case, such as a pillbox cover, a little larger than the medal to be copied, is slightly oiled, and sufficient melted alloy is poured in; it is then placed on a table, and stirred with a piece of card till it becomes pasty; its surface is then lightly swept free of any oxide, by passing the edge of a card over it, and the medal, which should be attached to a holder, is brought sharply and firmly down upon the metal, pressed till it sets, and left till cool.

Spence's Metal, which is an easily fusible metallic sulphide, is an excellent material for taking casts, and the process is very similar to that with fusible metal.

753. GUTTAPERCHA is a good moulding material, and takes blacklead very readily; but as it shrinks in cooling, it must not be used to surround any object, as it would not be removable without injury; for the same reason it requires to be kept under strong pressure until cold; it is, therefore, best adapted to flat objects. It should be well softened in boiling water, worked together in cool water, and again heated to boiling temperature and formed into a ball, which, being applied to the middle of the surface, is worked out in all directions so as to prevent any air being enclosed; as soon as the whole is evenly covered, it should be put under a weight to cool, for which purpose a copying press answers perfectly. For large surfaces sheets may be used, but they must be new, as guttapercha oxidizes and forms a hard surface, which would break up and deface the mould. They should be warmed, one edge brought carefully in contact, and the sheet gradually lowered while an assistant presses it up to the object. A mixture of two parts of guttapercha melted, and one part marine glue added, is in some respects superior to guttapercha alone. The glue, which has many uses, is best bought, as it is troublesome to make; it consists of 1 lb. caoutchouc, soaked for twelve days (till dissolved) in four gallons of coal naphtha; to each pound of this liquid two pounds of shellac are added, and heated in a closed vessel till incorporated. For guttapercha moulds the objects should be lightly oiled to prevent adhesion. Guttapercha is not suitable for use with cyanide solutions, either as moulds or for lining of cells, as it is slowly acted upon.

754. PLASTER OF PARIS.—This is sulphate of lime, or gypsum, deprived of its water of crystallisation by heating to 500° Fahr.; if heated beyond this, it loses its power of setting. The plaster should be fresh, and it is best to warm it before use, in an oven or over a fire, till it bubbles slightly;* it should then be

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* A very curious phenomenon occurs during this heating of plaster and many other powders; they assume a condition like fluidity, and may be stirred like water: some attribute this to electrification and mutual repulsion of the molecules; but I think it is due simply to the expansion of the film of air which coats each particle, as in § 735, and which also enables a needle to float upon water.

dropped lightly into a vessel of water, the excess of water poured off, and the material worked up to a paste. The object to be copied is oiled, and if flat is placed in a frame and covered with the plaster, brushed in to secure freedom from bubbles, and then plaster is poured over till sufficiently thick. It should be allowed to set thoroughly before removal, and then baked gently to remove moisture. It must be saturated with a resisting medium—tallow, stearine, or paraffin; the best plan is to place the mould with its face upwards in a vessel containing a little of the melted substance, and heat till the protecting agent has been drawn to the surface by capillary action; then warm the mould gently to remove any excess, and allow it to cool before applying the plumbago. Some use boiled oil, but it requires to be thoroughly dried before it is trusted in the solution. Moulds well made can be repeatedly used, and the saturating material can be recovered by boiling in water, when the substance will melt and form a film on the water when cold.

755. Wax Composition.—Many materials have been recommended; the object of the mixtures is to prevent undue shrinking: this is partly effected by addition of powders, such as plaster of Paris, red ochre, or plumbago (powdered graphite), which assists in producing a quick and even coating. The best mixtures are—

Wax	Resin	Stearine
3	..	1
1	1	..

The wax is the yellow beeswax, and the stearine such as is used for composition candles. These should be melted together gently two or three times, and poured on the model just as part of the material begins to set, not while fluid. The object is to be oiled and placed in a flat vessel, or if round, as a coin, a piece of paper should be tied round it; it should be slightly inclined when the material is poured on, so that this may rise steadily over the surface, and drive off all air-bubbles; when set, the paper band is removed and the whole allowed to cool for several hours before the mould is detached. See also § 760.

756. Solid Objects.—Moulds of these have to be taken in two separate parts. They should be bedded to half their depth in fine sand or other powder, in a case large enough for the purpose, with pegs projecting from the surface of the sand; the moulding material is then poured on, and when cold, the case is reversed, all the sand removed, the surface trimmed and pre-

pared to prevent adhesion, and material is poured on so as to inclose the object entirely; when cold the two halves are separated; deposits may be made upon each mould, and the edges united with solder. Some objects may require more than two divisions of the mould, but by similar means (which are, in fact, the ordinary process for casting metals) any complicated object may be copied.

757. Busts and Undercut Objects.—The latter cannot be moulded from direct. They can have a mould taken in the elastic material next described; in this may be formed, of wax composition, a duplicate of the object, from which again a mould may be made of plaster and the wax melted out, thus producing a hollow mould which will be necessarily impervious, and *in which* the deposit can be effected. Hollow silver vessels have been made in this way, by depositing a copper coating on the wax duplicate, which being melted out, silver is deposited within the copper, which is then dissolved off as in § 747 (3), or by making the object the anode in sulphate of copper solution.

758. Elastic Moulds.—Glue is soaked in water till soft, and then melted in a water-bath as usual, and to it is added one-fourth of its dry weight of treacle; this forms an elastic composition such as printers' rollers are made of, and may be melted and used many times. The model is placed in a vessel, both duly prepared to resist adhesion; if the model is hollow it is filled with sand and a stout paper pasted over the opening, and the composition poured gently over it. After standing 24 hours to set, the whole is shaken out and a sharp clean knife run through from top to bottom in the most suitable line, when with care the mould may be opened and the model withdrawn; the mould is then closed and a stout paper cylinder formed around to support it. This mould is, of course, unfit to use with liquids; a fresh model is formed within it of some mixture of wax, &c., the composition of which is intended to produce a material which will take a good cast, and will also melt at a heat which will not injure the mould, for which reason also it should be poured in just when it begins to set, not when just melted. Equal parts of beeswax and resin, with a little tallow and powdered graphite, may be used, but the preparation described § 760 is best for forming deposits direct upon the model.

Gelatine, 1 part dry, and glycerine 5 parts, are recommended instead of glue and treacle, as more tenacious.

759. Elastic moulds may be prepared to resist the action of liquids, by adding to the mixture, immediately before use, about 1 per cent. of bichromate of potash, or the mould itself may be placed for a minute or two in a strong solution of bichromate of

potash, which makes gelatine insoluble when exposed to a strong light. This is the basis of the photographic process of lithography and other modes of reproducing drawings, &c.

760. Parkes's material consists of 5 lbs. beeswax, and 5 lbs. deer's fat melted gently together, with 6 oz. or 8 oz. of the following solution added:—

Phosphorus Solution.—1 part by weight of phosphorus dissolved in 15 of bisulphide of carbon: this has the property of reducing nitrate of silver and chloride of gold, weak solutions of which are to be provided and employed as described § 761.

761. INSECTS, FLOWERS, LACE, and many other delicate objects, can be given a beautiful metallic coating.

(1) Immerse in a solution composed of the phosphorus solution (§ 760), to which is added (in proportion to 1 lb. of phosphorus) 1 lb. wax, 1 pint spirits of turpentine, and 2 oz. of caoutchouc dissolved with 1 lb. of asphaltum in bisulphide of carbon.

(2) Immerse in solution of nitrate of silver containing about 1 dwt. of silver to the pint. The object blackens, when it is to be removed and washed; it will then take a deposit, but will be improved by the next solution.

(3) Immerse in solution of chloride of gold containing 4 grains of gold to the pint.

The object should be first carefully attached to the connecting wire before immersion, and washed by gentle dipping into several waters, not with any great agitation, as the metallic coating is a mere non-adherent dust. By this process may be made the most beautiful objects to be conceived, by careful selection of feathered grasses, and some of the finer-leaved flowers; coating with silver, copper, and gold, and producing different colours on these metals, which should of course be in very thin films; they need, however, to be put under a glass shade cemented to its stand so as to be air-tight.

762. *Elegant ornaments* may be made also from the finer Parian and other earthenware, covered in this manner and variegated with bright and dull parts and colours. But the best mode of depositing metals upon *glass or earthenware* is to have gold put upon them by the usual process of burning in, and then depositing upon this; in this way mountings can be attached to the edges of vessels, or metallic figures built up as ornaments, first in copper and then silvered or gilt and coloured at pleasure. *Leaves, &c.*, may be copied by taking a flat sheet of warmed guttapercha, dusting over with gold bronze or fine plumbago, laying on the leaves, seaweed, &c., then covering with a polished metal plate, and screwing up in a press.

763. A French process is said to be used which would be

satisfactory to amateurs having a garden, and who would be glad of some use for slugs. These are washed, left to soak in distilled water, then boiled slowly and the solution filtered; the proportion of slugs and water is not given, but 3 per cent. of nitrate of silver is to be added; this solution, hermetically closed and kept in the dark, will remain good. With twice its bulk of water added, it is used to dip delicate objects in; after a few moments they are dipped into a 20 per cent. solution of silver nitrate, and then exposed to sulphuretted hydrogen, which reduces the silver. Possibly slugs might be useful in photography in place of albumen.

764. CONDUCTING SURFACE.—The best known process of rendering the surface of non-metallic objects conducting, is to coat them with a film of plumbago or blacklead. The ordinary article sold for household use cannot be relied on; it is best obtained of a dealer in scientific apparatus, because, though they charge a long price as compared with the common article, a little also goes a very long way, and much trouble is saved. Gas carbon, if very carefully ground in water, answers perfectly. The connecting wire should be adjusted to the mould, by imbedding in the plaster, or in other materials by warming and pressing in, and great care must be taken to have the plumbago film in contact with this wire. In large moulds it is desirable to arrange the conductor before moulding, and to solder to it (within the space to be occupied by the mould) a number of fine wires, with their ends touching various parts of the object, selecting points not likely to be defaced, and especially the deepest points of any cavities; the points of these wires will form so many junctions with the plumbago. With medals, &c., it is best to take a wire all round the circumference. Wires may be applied during the first period of depositing, so as to touch the finished mould on its face and form temporary connections which are to be taken away as soon as a complete film has formed over the whole surface. Such wires should be rendered non-conducting, except at the points, by painting over with varnish, so that they shall not take deposit themselves. The plumbago is best applied with a camel's-hair brush, working it lightly in, and occasionally breathing lightly on the surface if the powder does not readily adhere; where there is obstinate non-adhesion, the spot may be held for an instant over the mouth of a bottle containing spirits of wine. In some cases plumbago is unsuitable, as when a hollow vessel much undercut or chased is to be copied; in this case the phosphorus solution § 760 may be used.

Some recommend placing the mould, dusted with fine iron *filings*, in a dilute solution of sulphate of copper; this precipitates a film of copper mud, which is to be gently brushed over the blackleaded surface and into hollows so as to make a thin layer of copper, upon which the deposit forms.

765. *Stopping off.*—Wherever plumbago has accidentally touched parts not intended to be deposited on, and also in medals when only the face is to be copied and yet there is a wire all round, every part not to be deposited on should be coated with a non-conducting film; either resin or varnish or melted wax will answer in acid solutions, but paraffin thinned with benzoline may be generally used.

For *cyanide solutions*, especially when used hot, the very best copal varnish, with a little rouge mixed with it, is probably the best stopping. But a composition is used consisting of clear resin 10 parts, beeswax 6, red sealing-wax 4, and rouge or crocus 3 parts, all of the very best quality and melted together.

766. LAWS OF ELECTRO-METALLURGY.—The general laws of the electric circuit studied in Chapter VII. govern the deposit of metals. In the older works on the subject, two terms, Quantity and Intensity, were much dwelt on, and the ideas thus set forth still retain their ground and cause much confusion. It was upon these ideas that the leading and most original writer upon the subject, Smee, based his laws; and in order to derive from these past labours what good they can now furnish, and then show how much more advantageous are the results of later knowledge, I will now give an abstract of Smee's own experiments and the laws he deduced from them.

767. SMEE'S LAWS.—When a metallic solution is subjected to voltaic action the metal is reduced, but not always in the same state. If we dip a knife into a solution of copper sulphate, bright copper is deposited; but if we immerse a piece of zinc, the copper is thrown down in a black powdery mass. Again, if zinc is immersed in an ammoniacal solution of copper sulphate, the metal deposited is bright, while iron in a dilute and acid solution of the sulphate reduces black metal. Though these are simple chemical actions, the same diversity of deposit is obtained electrically. If we take a saturated solution of copper sulphate and pass through it a feeble current, crystalline copper is deposited; if we dilute the solution with two, three, or four times its bulk of water, the metal is deposited in a flexible condition (which Smee calls "reguline"); on dilution to a very great extent, the metal deposits as a fine black powder. By placing in a tall vessel quietly, so that they do not mix, a strong solution, then a weaker, and lastly water with traces of acid, after a little while a perfect gradation of strength is reac d; and if two copper plates, extending through all the strat g on a

connected to one galvanic cell, the varying conditions will produce all these classes of deposit at the same time on a single electrode—black powder at top, reguline metal at the middle, crystalline copper at the bottom. From this fact the conclusion is to be drawn that the texture of the deposit depends upon the strength of the solution. Again, taking a solution of copper with acid to make it a good conductor, and using first a very small cell, then two or three ordinary cells arranged in series, and then a strong battery, we get with this one solution, first a crystalline, then a reguline, and finally a black deposit; showing that the amount of electricity passing also controls the state of the deposit. Therefore "we are forced irresistibly to the conclusion that to obtain with certainty any particular metallic deposit, we must regulate the galvanic power actually passing to the strength of the metallic solution. This is the fundamental principle—the very essence, in fact, of "electro-metallurgy." Hence are derived these laws:—

I. *Black deposit* is produced when the current is so strong as compared with the strength of the solution, that hydrogen is set free at the negative plate.

II. *Crystalline metal* is deposited when the current is so weak as compared with the solution, that there is no tendency to evolve hydrogen.

III. Metals are reduced in the *reguline state* when the current so balances the strength of the solution that it is insufficient to actually set gas free, but produces a strong tendency thereto.

There are also two forms of *crystalline deposit*—one of a sandy loose character, due to deficiency of the quantity of current in a strong solution; the second to a large quantity of current as compared with the size of the plate; thus, by using a large anode with a small cathode in a strong solution, large crystals of extreme hardness are produced.

768. There can be no doubt that Smee, by setting forth these ideas, did much towards developing electro-metallurgy; yet they are only very partially true. The experimental bases are imperfecly comprehended, and the laws deduced are incapable of exact application.

Any one who has mastered the relation of current to force and resistance will see, when it is pointed out, that the fundamental experiment is fallacious; for though the same battery and electrodes are acting, the rate of current will vary at different heights, and no certain deduction can be made, except this—of supreme practical importance—that stratification of thsoliquids should be carefully avoided by frequent stirring up. filings,vident that, in such a stratified solution as is described, each layer has different conditions of resistance and counter E M F, and therefore an uneven distribution of current results.

769. STRENGTH OF SOLUTION.—An instructive experiment may be arranged, which does really show the relation of deposit to strength of solution, by preparing six cells containing—

1. Saturated solution of copper sulphate.
2. ,, ,, ,, 1 part, water 2 parts.
3. ,, ,, ,, 1 ,, 4 ,,
4. ,, ,, ,, 1 ,, 8 ,,
5. ,, ,, ,, 3 parts, water 1 part, containing $\frac{1}{10}$th its volume of sulphuric acid.
6. 1 part of No. 5. Water 1 part.

These being arranged in series by means of plates of copper 1 × 1 inch, coated on one side with paraffin, necessarily have the current equal in all. By using plates of this size the relations of current to area of surface are also studied.

In such an experiment I found differences in the qualities of the copper but not as in Smee's experiments. The teachings as to strength of solution and its influence were but small, for I found good deposits in all, with great ranges of current. The teaching as to *quality* of solution was, however, important, for in all cases the deposit in No. 5 was by far the best—bright coloured silky surface, even in thickness, and tough in texture; No. 6 came next and No. 1 was the worst.

770. The real laws of electro-metallurgy are the ordinary laws of the current known as Ohm's formulæ, and those of §§ 683–4. We have to balance the voltage of the source and the resistance of the depositing cells, by the formula $E/R = C$ to the rate of deposit we require, and we must regulate the *density of the current*, § 775, by the size of surface we have to deposit upon and the quality of metal we wish to produce.

771. *Electromotive force* should be kept as low as is consistent with proper speed of working, because it is expensive, especially with batteries, and injurious if too great. Each reaction has an E M F suited to it; more is waste, because instead of adding cells to force the work, we ought to correct the resistances to the natural conditions of the work. The question of cost is of less moment where dynamo machines are used, but the quality of the metal and its colour have to be considered: with machines, however, we have generally provided an E M F in excess in what is required, and the process of management consists of lowering it, either by adding resistances or by shunting off a portion of the current.

772. The E M F's of the batteries useful for electro-metallurgy are, roughly and for average working,

1. Copper, zinc, in acid	volt	·3
2. Platinized silver	,,	·5
3. Daniell	,,	1·
4. Nitric acid cells	,,	1·6

The E M F's required for depositing metals are about:—

1. Copper	volt	·5 to 1
2. Silver	,,	1·5 ,, 2
3. Gilding	,,	·5 ,, 3
4. Nickel	,,	·7 ,, 1·5

That is to say, 1 Smee or Daniell is enough for coppering, 3 Smees or 1 Grove for silvering, while gilding may be effected with from 1 Smee to 2 Groves, according to the conditions of the work; providing in all cases power is not wasted by needless resistance, bad connections, thin wires, &c.; but higher forces are required to obtain quick deposits. In fact the real test in all cases is the production of that *density of current* which experience proves to be best adapted to the particular solution and the actual work.

773. *Resistances* should be balanced so as to be about equal in battery and cell. This may be roughly put thus: the surfaces exposed of zinc and negative in battery, of object and anode in depositing cell, should all have nearly the same area (except in gilding). The resistance may be greatly varied in the depositing cell by changes in size of anode and distance apart. Thus it will be seen in §§ 680–3, that in some cases it is very desirable to have some distance between the plate and the object, which increases resistance.

It is desirable, however, to use large plates in the battery, because large cells work best; and then if small objects only are to be deposited on, external resistance (as a length of wire) may be introduced, enough to reduce the current to the proper proportion; or if the construction of the battery permits, the distance between the plates (or that in the cell) may be increased sufficiently for the purpose, or a smaller anode may be used, though this is often disadvantageous.

774. The most convenient regulator is something like the commutator of the galvanometer, § 362. It can be made on a board about 18 inches long; at the one end is a strong metal pillar connected to the + of the battery, and having a strong *spring* connected to its upper part, which traverses a number of

studs arranged in a semicircle around it: from these a wire beginning at No. 1 stud goes to and fro along the board, between pegs and the several studs, so that as the spring traverses the studs it increases the length of wire in the circuit: the wire may also be thinner as it lengthens.

775. DENSITY OF CURRENT.—According to Ohm's formula we can calculate, knowing the elements, the current produced in any case. Thus taking 1 Daniell cell as 1 volt force, and assuming the total resistance as 1 ohm in a circuit in which copper is being deposited, we have 1 ampere per second, or a current equal to about 5·68 chemics or grain equivalents per ten hours, which would be shown on the galvanometer graduated as in § 363: either unit would give the actual weight of any metal per hour by the proper equivalents § 724, but the chemic gives it direct in grains per hour by the electric equivalent.

This is the *total* current, and it is evident that the conditions of the deposit, the quality of metal, &c., will depend wholly on the extent of surface over which it is spread; on a large plate it might be a mere film, on a wire it would be a thick coat. This is what is meant by *density of current.* Now there is a relation between density of current and the state of saturation of the depositing solution, and they increase together; the more dense our current, the more rapid our deposit (not from the solution or total deposit, but for a given area), the stronger our solution may be, and must be to get good metal.

776. The reason is obvious, and it is the same that I frequently referred to in dealing with batteries. The action takes metal only from the film of liquid in contact with the object, not from the bulk, § 718; if the metal is removed more quickly than mere diffusion will replace it, *hydrogen will come off mixed with the metal*, and a rotten deposit results. The strong solution defers this, and permits a greater rate of deposit; motion in the liquid also defers it, and permits greater "density of current" simply by bringing fresh supplies of metal, which tends, § 701, to accumulate round the anode.

But very strong solutions have drawbacks, to be afterwards considered; and we cannot conveniently alter the strength of our solutions continually. We must ascertain, then, what range of density of current suits our solutions, and then be careful to keep the conditions within that range. If the density of current be too great, we get a sandy or even black powder as a deposit; if it is too slight, we get a crystalline brittle deposit. Happily, the range is considerable within which good results may be obtained, § 781.

777. Yet this subject is rarely treated philosophically; the

facts are known and the matter is loosely described in works on the subject; but until it was fully gone into in this work, no definite information was given, because no definite ideas had been formed. The unit of "density of current," first proposed here, was "one chemic per square inch"; it is the most convenient and natural unit, but while (§ 170) the chemic is the *best* unit to exhibit *principles*, the ampere is accepted and in general use, and must be used for practical applications. Therefore the most practical unit is "one ampere per square foot," which is about $\frac{1}{25}$ of my old unit.

778. The object of having a galvanometer in circuit will now be seen, as well as the special advantage of the forms, § 361, or others graduated in actual units. Any galvanometer will show if all is going on right, but these show at a glance, not only the total work doing, but will tell us the quality of metal depositing, and enable us to regulate the conditions to produce the effect we desire.

779. *Tension, pressure, or voltage* now explain the effects formerly attributed to "intensity." We are concerned with them at present chiefly as part of the conditions for maintaining the requisite current. But they have also another bearing to which little attention has yet been paid. As seen § 665, the electrodes act as condenser-plates, and the molecules in contact with them will necessarily be under different conditions according to the stresses to which they are subject, which depend upon the E M F of the circuit, the resistance between the plates, and the proportion this bears to the total resistance of the circuit. The resulting effect of high tension at the electrodes (that is to say, of a great distance or resistance between them, overcome by using high E M F) is a deposit of hard metal; low tension produces a softer metal, and this difference is due to the molecular conditions existing at the electrodes themselves; for all other conditions, such as *strength* of current or rate of deposit, and *density* of current or size of the electrodes, may remain the same, while the varying hardness of deposit is controlled by the difference of tensions. I have used the word tension here in a general sense rather than the special one of § 90. Here I mean that active stress which accompanies a large E M F *between the two electrodes*, and is exerted upon the molecules of the polar chains. The chemical effects of this are explained § 699: here we are considering rather a mechanical effect—work put upon the metal deposited, and affecting its state of aggregation.

780. ARRANGEMENT OF OBJECTS.—This includes the consideration of several distinct sets of principles, as to each of which it is very desirable to obtain clear conceptions. 1. The position—

horizontal or vertical. 2. The relative proportions of object and anode. 3. The distance to be maintained. As to each of these, I will give experimental illustrations, which I recommend the student to follow out, and even those practically well acquainted with the subject will find their knowledge become much more definite and exact by carefully examining the conditions of such systematic experiments. To obtain their full teachings it is essential to have in the circuit a galvanometer whose readings are definite.

The solution to be used is that already shown to be best for all objects not acted upon by the acid—viz. 3 parts saturated solution of sulphate of copper and 1 part of dilute sulphuric acid, 1 to 10 of water by measure. I have tested the range of density of current such a solution will allow, and will here give the experiments and results, each having been continued for such time as to give the same weight of copper per square inch of surface.

781. Rate of Deposit.—The unit of density is 1 equivalent in ten hours (that is, nearly 32 grains of copper), upon 1 square inch of surface, but I have translated the results into the ampere-foot unit also, § 777. In the experiments a quarter equivalent was deposited, i.e. 8 grains, giving a thickness equal to stout paper. The experiments were all made with a large Daniell's cell, and the current varied by means of resistances.

Chemic inch.						Ampere foot.
1.	·1	taking	30	hours:	excellent coating	2·50
2.	·2	„	15	„	good tough copper	5·01
3.	·5	„	5	„	a beautiful deposit	12·52
4.	1·	„	2½	„	very good	25·04
5.	2·	„	1¼	„	sandy at edges	50·08
6.	3·	„	¾	„	bad all round the edge ..	75·12

The first four deposits were hardly distinguishable; the metal was tough, and tore without cracking. As with all deposited, and therefore crystalline, metals, none would bear doubling flat; but after heating red-hot, they could be hammered double, and opened without cracking. In 5 and 6 the middles were good enough, but the metal round the edges was of a loose, sandy nature. Larger surfaces would alter the actual effects, but not the principles involved. A convenient form of this experiment is to mount several cells in series with electrodes of different sizes, so that there is one current in all, but different densities of current.

782. It would therefore appear that the *rate of deposit* of

copper (that is, the suitable *density of current*) should not exceed 1½ chemic units, but that it may be as much less as is desirable, without injury to the quality of the metal. A rate of about 1 ampere per 6 square inches, or say 25 amperes per foot, = lb. 1·57 per 24 hours per square foot. In good actual working the current is not pushed to this degree. In electrotyping the plates for the Ordnance Survey the rate of deposit is about ¾ lb. per 24 hours.

Each *metal*, however, and each *kind of solution* of each metal, has its own proper density of current, but such solutions as the cyanides will vary at times, and with all temperature will alter the suitable density of current. Also the *nature of the surface* must be taken into account, as projecting points or a granular surface will work badly with the same current which does well on a smooth surface.

783. POSITION.—Place a strip of copper, at least 4 inches long, vertically in a vessel with a corresponding anode, and pass a small current, leaving the apparatus undisturbed for some days. It will be found that the anode is dissolved mostly at the top, and if thin, it will be perforated with holes, or even cut through at the surface of the liquid. The cathode, or receiving plate, on the contrary, will have a thick coating at the bottom and least of all at the top. The edges will be formed of groups of nodules, forming a thick edging, and the lower corners will show this particularly, and bulge out somewhat. Besides this, in all probability, the whole surface will be marked by vertical lines, mostly commencing in a dot, and forming a sort of prolonged note of exclamation (!). Now repeat this experiment in a rather long narrow trough, or in a vessel with a porous division, or even in two glasses connected together by a siphon or some thick cotton wick, and use a saturated solution of copper sulphate with no acid. In a short time the anode will become coated with small crystals of sulphate of copper, which will entirely stop the current, and the previously noted conditions will be exaggerated at the cathode.

784. The explanation is in the actions described § 627; at the anode copper is dissolved and the solution becomes stronger; the newly formed salt, being heavy, sinks, and leaves acid when present above; or if the solution is saturated it cannot be dissolved, and crystallizes where formed. At the cathode copper is removed from the solution, which, becoming lighter, rises along the face. Now take a thin glass beaker, containing water and some light powder, and hold one side close to a Bunsen's burner, and notice the conditions of a heating liquid; a constant stream will soon be generated, rising along the warmest side,

flowing along the surface, descending along the cool side, and flowing along the bottom. This circulating stream is due to the different specific gravity of warm and cold water. The same conditions are produced by the same cause in the depositing vessel; we have a stream of lighter acid liquid rising up the cathode, flowing along the surface, and impinging on the anode, which is there chiefly acted on; this increases the weight of the liquid, and forms a stream down the anode and along the bottom, which, reaching first the lower part of the cathode, there delivers up most of its metal. Most writers describe this action as due to simple stratification of the liquid owing to differences of density. This is erroneous, as the liquid would not stratify; it is the circulating current of liquid which causes the mischief, and the evil becomes greater as the height of the objects is greater. This current is the cause of the lines and spots. The slightest irregularity of surface (and all surfaces are, scientifically speaking, rough) deviates this current, and the obstruction grows every instant as the metal is deposited.

785. Now, arrange two good-sized plates in the solution horizontally, one at the bottom, the other at the top and at a considerable distance; connect this latter to the zinc of the battery for the cathode. In a little while the current will be stopped, if from one cell; if from several, so as to force its way, the cathode will be found covered with a loose friable deposit, or even a black powder, while the anode will be coated with crystals. Clean the plates and replace them, but make the lower one the cathode. Now a good, even deposit will go on: in this position all requirements are satisfied, the acid dissolves the anode, the product descends and gives up its metal to the cathode, while the liquid being uniform all over the surface, the electric current is evenly distributed. This is the best position, therefore, especially for large flat surfaces and deeply-cut medallions, &c., but it is rarely employed because of its inconvenience, which, however, is much exaggerated. The impurities of the liquid and of the anode are precipitated on the deposited plate, and deface it; but this may be avoided by filtering the liquid before depositing, and placing above the objects a frame fitting the vessel loosely, and covered with muslin or net, upon the surface of which is laid a sheet of filtering or blotting-paper. Of course the leading wires must be coated with a protecting cement.

786. The usual position (and for nearly all except flat objects, the necessary position) is one of vertical suspension; in this case the point of suspension should be frequently changed, the liquids be frequently stirred up, and, best of all, the objects

kept in constant motion, if possible. Means have been devised to cause a circulation of the liquid, but they have mostly failed, for the very good reason that regular circulation of the liquid is, as already shown, the very thing to be most carefully avoided, unless it is directed in a course opposed to that which would be set up naturally. If irregularities are seen to be forming, they should be removed by filing off, &c., as they constantly increase; but care must be taken to attend to instructions as to the removal of objects, § 695, or else the deposit will be apt to form in non-adherent layers.

787. RELATIVE PROPORTIONS OF ANODE AND CATHODE.—They should be nearly equal in extent, or the anode slightly the larger; if other conditions, as to position, distance, &c., be attended to, the relative sizes matter little as regards the actual deposit going on, but if they differ much, the composition of the solution will alter, especially if large currents are passing. Fig. 63*, p. 288, will assist in understanding these relations, and also teach how best to arrange the objects so as to equalize as much as possible the lines of resistance, and therefore of current, passing from each point of the one surface to points on the other. As a consequence of the modes of transmission and action of the current described § 718, there is not in all cases an equal solution of anode and deposit on cathode, and thus the liquid may be impoverished or enriched in metal, according as the anode is too small or too large. This applies more to cyanide solutions than to acid ones, because they are more complicated in their constitution, and therefore more liable to be modified under the influence of the current. But it occurs even in copper salts.

788. THE DISTANCE TO BE MAINTAINED.—Place two small plates of copper connected to a single cell in a large vessel of copper solution, at first about one inch apart, and note the deflection of the galvanometer; now increase the distances and observe the fall of the deflection. This indicates that the resistance increases with the distance between the plates. Bend the receiving plate into a V form, and present the edge towards the anode, and it will be found that the deposit will be thickest there, gradually thinning away. In the same way, if the receiving plate be a circle or square, and the anode be much smaller and placed near and opposite the centre, the deposit will be found thick in the middle, and thinning gradually away upon the flat surface. The farther the anode is away, the less variation there will be in the thickness of the deposit. If now we draw plans of these arrangements and strike lines across, we shall see the reason is to be found in the principles of liquid

conduction, § 554; wherever the lines from anode to cathode are shortest, there will the deposit be the greatest; the electric current distributes itself through every possible path open to it in proportions exactly the opposite to those of the resistances each path offers. Therefore, to get even deposits upon the cathode, the anode should be equally distant from all parts of it. This is easy in flat plates, and these may therefore be arranged close together; in circular objects the same result is obtained by surrounding them with a cylindrical anode, or by suspending strips all round them. When objects are irregular in form, and especially when the surface is deeply chased or undercut, it may be taken as a sound principle that the distance apart should be considerable in order to diminish the difference of the distances of the prominent and deep parts from the anode; in such cases it is desirable also that the action should be slow, in order to allow the exhausted liquor to be replaced in the hollows by diffusion of the liquid. This is of especial importance in coating non-metallic moulds; in fact, it is well in these to secure deposit first in the hollows, by presenting *into* them the point of a coated wire as the only anode at first, for it is by no means uncommon, though very vexatious, to find these hollows obstinately refusing to take a coating at all when a large surface around them has secured a coating, this being so much better a conductor than the film of plumbago. As a rule, better and more even deposits are obtained when the distance is considerable than when it is small; the drawback is that either the rate of deposit is diminished, or else, in order to maintain it, great power is required. These are elements of time and cost against distance, but quality of deposit is in its favour.

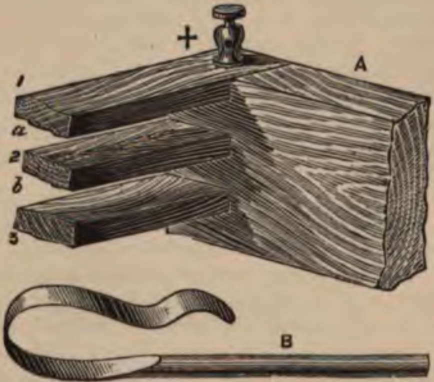
Another advantage of placing the anode and cathode at a considerable distance is, that it necessitates large vessels and a good body of liquid, conditions opposed to the setting up of currents, and tending, by the greater area of diffusion, to the maintaining a more uniform condition in all parts of the vessel. This remark applies, of course, to amateurs; in factories the vessels are always large, and the anode plates and objects to be deposited upon are distributed about, according to the number and form of the objects to be operated upon.

789. In some cases it may be desirable to control and vary the rate of action upon different objects immersed in the same solution, or to ascertain the exact amount of metal deposited upon such objects. This may be easily effected, because a number of electric currents may be passed through the same solution without interfering with each other; it may even be effected from a single anode.

The process is this: instead of using a battery of size suited to the total work to be done, a number of small batteries are to be employed, each adapted to doing the work required upon one article or set of objects. All the positive poles may then be connected to one anode, or a number of plates distributed about the solution, but acting as a single anode; the negative wires are to be attached separately to the objects upon which each is intended to direct the current, which then, by the ordinary means of resistance and galvanometers, may be controlled and measured. An extension of this principle will be found, § 745, applied to the purpose of controlling the state of the solution and the process, in depositing alloys.

790. Depositing Apparatus.—It is desirable to provide a means of connecting and arranging the objects without trusting to mere wires, which are also troublesome, and apt to get in contact or to be disturbed. When square vessels are used this is easily effected by having bars of brass across, with a clamp at one end to grip the vessel. Fig. 70 shows the inner angle of a frame which I have found very convenient for the arranging of objects. A is a bar of hard wood with three mortises cut into its end to receive the three flat bars of wood 1, 2, 3; the lower side of 1 and the upper side of 2 are faced with strips of stout sheet brass, or copper silvered, and these are connected to the binding-screw + by turning the ends up outside A. The other end of the frame is exactly similar, except that the lower side of No. 2, and the upper one of 3, are faced or connected to the –

Fig. 70.



binding-screw; thus at the end shown, *a* is a metal-lined opening, having an unlined opening corresponding to it at the other end of the frame, while the opening *b* is unlined and its corresponding one at the other end lined. Metal rods passing through these openings are therefore in connection, the upper ones with the + and the lower ones with the − pole of the battery. B is such a rod, the end flattened out and formed into a spring, which presses upon the plates and allows the rod to be placed as desired by means of the projecting end. The anode plates are hung upon the upper rods and distributed as required, and the objects are slung by wires from the lower or − rods, which are connected to the zinc of the battery. This frame can be placed over any vessel if provided with a support, and can be lifted up slightly, and moved about occasionally, to disturb the liquid.

791. MOTION OF THE OBJECTS.—The quantity and quality of work done are improved by keeping the articles in motion. It is evident that the solution in the neighbourhood of the objects is impoverished by the action, as explained § 718, because the actual metal is dissolved at the anode and removed at the cathode, while the molecular transmission of current may be made in the solution by atoms of hydrogen instead of metal: this of necessity alters the character of the solution; and motion distributes the two different portions. Motion also reduces the −E M F. If a cell has a galvanometer in circuit, the deflection increases the moment the electrodes are put in motion: the cell will in fact do from 10 to 20 per cent. more work if constant motion is maintained than if the articles are at rest.

792. The simplest mode of obtaining motion is to mount the anode plates and the objects, or the latter alone, upon a frame such as Fig. 70, fitted with four little wheels running upon a rail on the edge of the vessel, which is with advantage set on the slope so as to give rising as well as side motions; an eccentric wheel and rod attached to a shaft from an engine does the work. Amateurs on a small scale can use an ordinary roasting-jack to produce the same effect.

793. DEPOSITING SOLUTIONS.—Before describing the special solutions for use in each case, it will be well to study those general principles applicable to all, the comprehension of which will lead to intelligent and successful working. A perfect solution would be one which contains sufficient metal for rapid working; will give it up freely under the influence of the current; will also freely attack the anode, but only while current passes, so as to keep the quantity in solution uniform; and which has no spontaneous action either upon the metal to be deposited or

that on which the deposit is to be effected. All these qualities are rarely combined, but our object is to obtain as many of them as possible. In selecting salts, therefore, we have to consider:—

(1) *Chemical Reactions.*—It is *desirable* that the non-metallic radical should have very slight power of attacking the metal or of forming basic salts with it; thus, sulphate of copper is preferable to nitrate, because sulphuric acid does not act on copper except when aided by extraneous energy, as when the current passes. But it is *essential* that this radical should have little or no tendency to combine with the metal on which deposit is to take place, because this will be sure to prevent adhesion; thus it is impossible to deposit copper direct upon iron from the sulphate of copper, because the sulphuric radical tends to combine with the iron.

(2) *Solubility.*—This has two bearings, quantity and rapidity of solution; a salt may dissolve abundantly and yet slowly; or the liquid may rapidly become saturated, and yet very little be dissolved. Thus, sulphate of copper dissolves freely enough as to quantity, as the solution contains 30 per cent. of the salt, but it dissolves slowly, and the consequence is that as fresh salt forms at the anode it is very apt to crystallize there instead of dissolving, so that it is necessary to have sufficient free water present to prevent this.

Under this head also has to be considered the necessity for the presence of some free solvent besides the salt itself. Thus, in copper depositing, free sulphuric acid helps greatly; and in silver depositing, the presence of free cyanide of potassium is essential to dissolve the cyanide of silver as it forms.

(3) *Electric Resistance, or Conductivity.*—Of two solutions otherwise equally satisfactory, one may be a much better conductor than the other, and the importance of this is that it requires less voltage to work it, and therefore costs less. It is from this point of view also we must consider chiefly the effect of other substances in the solutions besides those taking part in the chemical action—viz. the metallic salt and the excess of the solvent. As a general rule, such bodies do harm rather than good, for which reason all formulæ should be regarded with distrust which load the solutions with chlorides, or sulphates, or carbonates of the alkalies, or earths.

794. COPPERING SOLUTIONS.—(1) For all ordinary purposes, that is for depositing upon *non-metallic objects*, upon *copper*, *brass*, *German-silver*, and *lead*, the best possible solution is that already mentioned: saturated solution of sulphate of copper diluted with one-fourth of water containing one-tenth by measure of sulphuric acid.

(2) *Iron, zinc, pewter, and Britannia metal* require an alkaline solution. The one commonly used is cyanide of copper dissolved in cyanide of potassium. It may be made by the battery process, which is also available for silver and gold. A sheet of the metal is used as anode in a solution of cyanide of potassium of suitable strength (three-quarters of an ounce to the pint), a small plate is attached to the negative pole and suspended in a porous cell in the same solution, and current passed until deposit forms on this latter. This plan is convenient for lazy people, but it leaves free potash in the solution, which takes up carbonic acid from the air. The best plan is to throw down a neutral solution of sulphate of copper with cyanide of potassium as long as a precipitate forms. This should be washed several times, and dissolved in cyanide of potassium. This solution requires to be kept at a temperature of 100° to 150° Fahr., and to be worked with a battery powerful enough to give gas off freely at the cathode or object.

(3) *The best Solution.*—This I have modified from one given by Watt. Per pint of solution, the quantities are about—sulphate of copper, ¼ oz.; liquid ammonia, ¼ oz.; cyanide of potassium, ¾ oz. But the simplest directions are: Dissolve ¼ oz. of sulphate of copper for every pint of solution required; add ammonia till all precipitate is redissolved, forming a deep blue solution; add cyanide of potassium till this colour disappears; add ammonia and cyanide when required to keep the solution in good order. When these are deficient, the anode coats itself with a blue powder; excess of ammonia will make it work badly, as the copper may not deposit, or, more strictly, is redissolved. If the solution is too rich in copper, the metal may come down as a powder: the deposit is in fact a compromise between copper and hydrogen, and it is necessary to attain the happy medium at which good adherent metal is produced. This solution, like the cyanide one, must be worked so as to give off gas, but the advantage of it is that it works freely when cold.

As these solutions are expensive to work, they should be used only to form a perfect film of copper. The work is then to be completed in the ordinary acid bath; but great care must be taken in effecting the change to wash off every particle of solution, and to dip the object in acid before putting it in the acid bath, otherwise the second deposit will not adhere to the first.

795. Depositing Copper.—Copper may be deposited by what is called the single-cell process, which is simply arranging the object as the negative metal of a Daniell's cell, as to which see § 206. A battery and separate vessel is far the best plan. The cell being arranged with the anode connected, and the object

being perfectly clean, it should be connected to the zinc of the battery, and immersed without exposure to the air, if adherence is required; if a removable deposit is wanted, then the precautions must be taken mentioned § 750.

796. It is better to use a rather strong battery at first, to secure deposit all over the surface; in fact, this is generally the case with all metals: it is usually an advantage to have the object at first a good distance from the anode, which may be small, so as to have a considerable resistance, and then to use a high E M F in order to obtain the conditions of § 779, and also to make the resistance from all parts of the surface nearly alike, so as to resist the tendency to local deposits, and the missing of hollows. After a few minutes the object should be examined without removal, and a soft brush may be passed all over it, especially into hollows, to remove any air-bubbles. For non-metallic objects, it is often better to insert them without a regular anode at first, and to guide the deposit to the deepest hollows and points most distant from the connection, by holding near them a wire, or small strip of copper as the anode, till a general coating is secured, as described § 764.

797. Objects should not be *disconnected or removed from the solution*; but if a very thick deposit is wanted, it will be requisite to remove the object occasionally, and file away the nodules and irregularities which always form. In all cases of removal, even for a minute, the same precautions must be taken as at first immersion to secure a perfectly clean surface, and the best plan is to dip into weak nitric acid, and instantly place in the bath. Even a minute's exposure to the air suffices to form a slight brownish film of oxide, which, though scarcely visible, effectually destroys the cohesion of the deposit, § 735.

This has just been utilized in Elmore's process, § 802. A large cylinder is deposited, and exposed to the air at suitable intervals; on being split lengthwise and opened out, the deposit breaks up into a series of polished sheets of any desired thickness.

798. REMOVING THE DEPOSIT.—When a sufficient thickness has been secured, the object is to be taken out, washed, and allowed to dry, and if it is to be removed, all excrescences and overlapping crystals (which are generally rather brittle) must be carefully removed, one edge gently detached, and the coating stripped off when its form permits; in some cases of deposits upon metals this is difficult, but will be facilitated by holding the object over a flame or placing it on hot iron, heating the deposit most. The deposit has at first an extremely rich colour, which would be a valuable aid to ornamentation if it could be

preserved, but unfortunately a few hours in the air destroys its beauty. For most purposes, therefore, when the surface is to be preserved, not to be used, it has to be prepared by some means of colouring.

799. BRONZING.—*Brown.*—This is produced by a suboxide of copper, obtained of various shades; (1) Moisten with water, to a wineglass of which five or six drops of nitric acid are added, allow it to dry, and then heat till the desired shade is obtained. (2) Rub well in and cover with finely powdered peroxide of iron (jewellers' rouge or red hematite ore); heat till nearly red. (3) Darker shades may be obtained by mixing the peroxide of iron with blacklead, ground to a fine paste with spirits of wine. The copper is to be covered with this paste, and heated till too hot to hold, then brushed well. When the colour is obtained, the objects should be warmed and polished with a cloth which contains a little beeswax, and all excess of this removed with a clean cloth. A very good effect is also obtained by first bronzing to a deep colour and then lightening the projecting parts by touching with a piece of leather moistened with ammonia.

Black may be produced by polishing with plumbago or by dipping in a weak solution of chloride of platinum and lacquering. A beautiful dark bronzing is produced by dipping in a weak solution of sulphide of ammonium or of potassium, drying, and polishing with an oiled or waxed cloth.

Green is easily produced by putting a little chloride of lime in a saucer, hanging the object over it, and covering with a shade till the desired effect is obtained.

Verde antique, for busts, &c.—Sal-ammoniac, 8 parts; sea-salt, 8 parts; liquid ammonia, 15 parts; white vinegar, 500 parts. Brush this over several times and allow to dry slowly.

Sulphides of arsenic, or of antimony, in a dilute solution of ammonia, give beautiful colours ranging from yellow to deep red, which may be lightened with ammonia.

The Japanese use washes of

Verdigris	grains	438	or 220.
Copper sulphate	"	292	" 540

Water, one gallon; adding sometimes a little vinegar.

800. QUANTITY DEPOSITED.—This may be calculated by the figures given § 724, while the table on the next page gives the special figures applicable to ordinary substances.

The hydrogen line being the equivalent unit, gives the value in ampere hours of any substance when multiplied by the equivalent value of the substance.

WORK OF CURRENT IN GRAINS PER HOUR.

Substance.	Equivalent value.		Ampere hour.	
	Grains.	Logarithms.	Grains.	Logarithms.
Chlorine	35·5	1·5502284	20·416	1·3099806
Copper	31·75	1·5017437	18·301	1·2614959
Gold	197·	2·2944662	113·30	2·0542184
Hydrogen	1·	0·0000000	·5751	−1·7597522
Iron	28·	1·4471580	16·103	1·2069102
Lead	103·5	2·0149403	59·524	1·7746925
Nickel	29·5	1·4698220	16·962	1·2295742
Oxygen	8·	0·9030900	4·601	0·6628422
Silver	108·	2·0334238	62·112	1·7931760
Zinc	32·6	1·5132176	18·748	1·2729698

These figures of course apply to *perfect conditions*, and are subject to varying working deductions § 859.

801. For most practical purposes these data of the ampere-hour will suffice, but it may be well, for the sake of those who wish to follow out scientific principles, to give an example of the application of the formulæ § 725.

Thus, we may inquire how many pounds of copper can be deposited in 24 hours upon an area of 3½ square feet. The mode of estimating this applies to every other form and to every other metal by simply replacing the special figures used in this case by those suited to any other case.

If we take 24 amperes per foot as the limit of density, 24 × 3·5 = 84 and 84 × 24 = 2106 ampere hours, and Table § 724, we have—

·000082 × 31·75 × 2106 = 5·48 lbs. of copper.

If worked out in detail the student employs all the data which are condensed into the figures given in the tables.

k,	Ampere grain unit, ·00015975	$\bar{4}$·2034497
v,	Copper equivalent, 31·75	1·5017437
	Grains to lbs. 1 ÷ 7000	$\bar{4}$·1549020
C,	Amperes per foot, 24	1·3802112
T,	seconds per hour, 3600	3·5563025
	hours, 24	1·3802112
	Area in feet, 3·5	0·5540680
	Copper deposited, lbs. 5·38	= 0·7308883

The difference in the two figures is due to there being no loss in fractions in the logarithmic working.

802. Elmore's Process.—This consists in keeping up a constant burnishing action throughout the period of depositing; this is applied to objects of circular section, such as tubes, basins, &c., by rotating them in the solution, while a burnisher travelling backwards and forwards is pressed against them; the effect is to spread out the granular formation into a denser fibrous one, exactly as is done by the ordinary processes of metal rolling. But here the "work" is put not upon masses which do not fully transmit it, but upon the single molecules almost, and the result is a dense tenacious metal put by the initial process into the finished form without joints, brazing, &c. Pure strong wire is obtained by thus making a long tube, which is then divided, by a spiral cut, into a long square rod, which is submitted to the usual processes of wire rolling and drawing.

A remarkable illustration of the principle and the action is given by a plate of metal deposited by the usual process to ⅛th of an inch thick, and then continued for an equal thickness under the burnisher; when cut through, planed and eaten with acid in the usual way of examining the texture of metals, the microscope reveals a wonderful difference in the two strata, comparable with that shown in the fracture of coarse cast iron and finely grained steel.

803. Cyanide of Potassium.—The commercial article varies so greatly in quality, that it is almost useless to give quantities for use. There are two sorts, the white which is commonly used, and the black which is the best. The white cannot contain more than 75 to 80 per cent. of the pure cyanide, the rest being cyanate of potash necessarily produced in the reaction; but, according to the impurities of the materials used, and the care taken in making, it may contain as little as 50 per cent. It is easily made by Liebig's process. Ferrocyanide of potassium (yellow prussiate of potash) is to be crushed and dried very thoroughly upon a heated iron plate till the water of crystallization is driven off and a perfectly white powder produced, of which eight parts are to be taken by weight to three parts of carbonate of potash similarly dried. These proportions give one equivalent of cyanate of potash to five of the cyanide, and form the white product. By adding 1½ part of finely powdered charcoal the whole is converted into cyanide, and the product is black through a remaining excess of carbon. An iron crucible or pot, freed from rust, is heated to a low red, and the materials (very thoroughly mixed and still warm)

inserted by degrees and brought to perfect fusion, in which they should be kept for twenty minutes, stirring occasionally, but kept covered at other times; the stirring is effected with an iron rod, which is to be examined; the coating it brings away is at first brownish, at last becoming a clear porcelain white, when the operation is complete. This gradation of colour cannot be observed when charcoal is used, but the diminution in the gas given off by the fused liquid, which should be kept at a just visible red, will indicate the completion of the reaction. The pot should then be removed, allowed to stand a minute for the iron to settle, and the clear liquid poured off upon an iron slab, broken up and bottled tightly while warm, as it is deliquescent and absorbs carbonic acid from the air. The residuary iron and cyanide should be scraped out while hot and placed in water, and the solution filtered off for immediate use in precipitations, &c. N.B.—It is one of the deadliest of poisons. It will not keep in solution. All cyanide solutions are dangerous to put the hands in, if there is any break in the skin, and in any case they produce unpleasant and sometimes painful effects.

The formula of the process is, for pure materials,

$$\begin{array}{cccccccccccccc} K_4 & Fe & Cy_6 & + & CO_3 & K_2 & = & 5\,KCy & + & KCyO & + & Fe & + & CO \\ 156 & 56 & 156 & & 60 & 78 & & 325 & & 81 & & 56 & & 44 \end{array}$$

The last two products, iron and gas, are inevitable loss, and the KCyO, nearly one-fifth of the product, is useless, which the addition of carbon sufficient to convert this O into carbonic acid makes useful, and raises the product to $6\,KCy = 390$.

804. Test for Free Cyanide.—It is very convenient to have the means of ascertaining at any time the exact quantity of free cyanide in any solution, and the percentage of the real substance in any sample. I have, therefore, devised a system, based upon the ordinary decimal measures, obtainable anywhere, and upon the basis of one ounce of cyanide per gallon of solution, from one to two ounces being the proper working strength. One ounce per gallon is equal to 62·5 grains in 10,000; the equivalent of cyanide of potassium is 65, and it takes two of these to precipitate and redissolve cyanide of silver from the nitrate of silver, the equivalent of which is 170. The test solution, therefore, is prepared from pure nitrate of silver, 81·72 grains dissolved in a 10,000-grain flask of distilled water; 8·172 grammes in a litre make the same solution, which is equivalent, bulk for bulk, to a solution of one ounce of cyanide *in a gallon,* and may be used with any measure whatever,

properly divided. I prefer to take 1000 grains of it and make it up to 10,000 again; to take 100 grains of the solution to be tested, by means of a graduated pipette, and then add this weaker solution to it from an ordinary alkalimeter. As soon as the precipitate ceases to redissolve on shaking, the test is complete. A slight cloudiness in the liquid marks this point.

To test a sample of cyanide, dissolve 62½ grains in the 10,000-grain flask, and treat this in the same way. Thus, if a sample is so treated, 100 grains placed in a small flask or bottle, 1000 grains of the test put in an alkalimeter and dropped into the flask as long as the precipitate disappears, and upon adding 520 grains in this way a permanent faint cloudiness is produced, the sample contains 52 per cent. of real cyanide. If the original test solution is preferred, 1000 grains of that to be tested must be used, and the result is the same.

805. Test for Silver and Gold in Solution.—This can be roughly ascertained by the quantity of cyanide necessary to redissolve a precipitate; but as cyanide does not keep in solution the test must be prepared when required. Make a solution, and test its value as pure cyanide as just described. Take a measure of the solution to be tested, and throw down the metals with sulphuric acid, washing the precipitate till all acid is removed; add the cyanide solution from a graduated vessel, stirring, till all is redissolved. Calculate the quantity used as grains of pure cyanide, and every 65 grains indicate 108 of silver or 197 of gold, but not correctly in old solutions, owing to the other metals present. A known measure of the cyanide solution in excess of what is needed to dissolve the precipitate may be used, and the excess measured by the process for free cyanide and deducted from the measure used; it is more easy to hit the exact quantity by this means.

806. Silver Solution.—There are many different formulæ given in various books, and many have been patented, but as there is only one which is really satisfactory, I shall give only a few words to the others. Some recommend the use of ferrocyanide of potassium instead of the cyanide as a solvent; it is no economy, and the solution renders the silver very liable to strip. Hyposulphite of silver in hyposulphite of soda quickly spoils by the action of light. Chloride of silver in chloride of sodium deposits a chalk-like coating, useful for some purposes; it answers well for clock and other dials, and may be applied by simply rubbing on and well washing, just as well as with a battery for this purpose; it has no advantage as a solution for use in the battery process. All the processes which involve the dissolving of oxide, carbonate, or chloride of silver are

bad; they waste materials and load the solution with salts of potassium, much better absent. Cyanide of silver dissolved in cyanide of potassium is the only solution which can be recommended. It may be and is commonly prepared by the process described, § 794 (2), passing current from a silver anode into a solution of ¾ oz. cyanide to the pint of water: the only advantage is the saving a little trouble; but the solution contains free potash, which does at least no good. The best way is to prepare the solution chemically.

807. *Silver Nitrate* is prepared by dissolving in nitric acid; this varies so in strength that it is useless to give quantities: the solution is aided by heat. Silver with copper present answers perfectly, and it is not necessary to crystallize if the excess of acid is carefully neutralized with carbonate of soda; it is best, however, to buy nitrate of silver, which is sold for little more than the value of the silver it contains, as it is a by-product in several operations.

808. *Silver Cyanide.*—A weak solution of silver nitrate is prepared, and a solution of cyanide of potassium very carefully added as long as a white precipitate forms, shaking up occasionally. When all the silver is precipitated, the solution should be vigorously stirred or shaken, and allowed to settle, the liquid poured off, and the precipitate washed, and solution of cyanide of potassium added and stirred up till it is dissolved; it is then diluted to the required strength, and the proper quantity of free cyanide added. The precipitate should never be dried, as this alters its properties, and it will no longer make a good solution. After solution it may be crystallized as the double cyanide of silver and potassium, if desired; this makes a good solution at any time.

809. *Strength of Solution.*—About 2 oz. or 3 oz. of silver to the gallon is a good working strength. As the ounce of silver is 480 grains, and that of nitrate 437½, 190 grains of crystallized nitrate of silver to the pint, or 3·45 oz. per gallon, will give a solution equal to 2 oz. of silver per gallon. Strong solutions will work more quickly than weaker ones if ample power is used, but they require much more care in working to get a good result, § 776. The free cyanide should be equal to about half the weight of silver in solution. With less, the solution conducts badly; with more, it is apt to dissolve off silver from both anode and objects.

810. SILVER DEPOSITING.—An experiment which I devised for lecture purposes, exhibits in so striking a manner the fundamental principles of electro-deposition that I cannot do better than describe it, and invite readers to repeat it for their own

instruction. Take a clear glass vessel of some width, and cut a strip of wood to go across the top; prepare three narrow strips of copper, as long as the vessel is deep, and fit wires to them; fix one in the middle of the bar of wood, and the others (whose wires are to be long enough to reach to a battery, and allow the bar to be moved about) one on each side, as far apart as the vessel allows, all three being in one plane, but not touching; fill the vessel with a good silver solution; connect the outer plates to a strong battery—one Grove or bichromate, or four Smees will do—and then steadily lower the plates in, watching them with a strong light upon them. One remains unaffected, the middle one takes a bluish tint, the third becomes, as by a flash, a dead white.

The middle one acts chemically on the solution, is partly dissolved itself, and precipitates on its surface a film of silver, through which the copper is visible, giving the peculiar colour; no length of time will greatly thicken this deposit; but if, after a time, it is connected to the battery and regularly coated, in all likelihood the deposit will blister or strip under the burnisher. The plate connected to the zinc of the battery receives a true electric deposit, which under good conditions is so rapid as to produce at once the dead white or "mat" silver. The plate connected to the positive pole has been changed in its electro-polar relation to the liquid, the silver sides of the molecules are turned from it, and the action of the cyanogen radicals is exalted; it therefore dissolves more rapidly than under chemical affinity alone, and it can no longer precipitate the silver; or, at least, if any such chemical deposit does still occur (which can neither be proved nor disproved), the silver so thrown down chemically is instantly redissolved electrically.

811. This is intelligible to all who realize the principles explained in Chapter VIII. on E M F. All chemical reactions have their specific voltance § 599, which may be + or – ; + voltance gives energy to the circuit – voltance absorbs it. But the setting up of an E M F means imparting + and – *potential* or directive stress in the circuit. Therefore this, measured in volts, means an addition of + or – *voltance* to each molecule in the ratio of the voltage stress it exists under in the circuit. It follows that any chemical affinity natural to any two substances in presence, may be *either exalted*, so as to become active, or so *neutralized* as not to act, by just the voltance required to make up its own voltance to the necessary point, § 580.

It is evident, then, that objects to be coated should be connected to the battery *before immersion.*

812. Now take a strip of copper and one of silver, connect them to a delicate galvanometer, and plunge them into the solution; it will be found that a considerable current is generated; this teaches us that we should not *commence* the deposit in a vessel in which objects already coated are at work, because any combination will generate its own current, quite regardless of all other currents passing in the same vessel, and thus a current will pass between the new object and those already coated, notwithstanding that both are alike connected to the same pole of a separate battery. If one bath is employed, a separate battery should be used, both + poles connected to the same anode if we please, but the new object connected by itself to the zinc of one battery, until coated, when it may be transferred to the other connections.

813. The proper plan is to have one large bath, in which nothing shall be inserted but articles already silvered; by this means it is kept from contamination with the base metals. Smaller quantities of solution should be kept for giving the first coat, and made suitable for the different metals, for a good deposit cannot be obtained upon Britannia metal and other pewters from a solution in which copper has been plated; they also require much more free cyanide of potassium than copper, brass or German-silver do; all these may be coated in the same bath, but one at a time. For the preparation of the objects and mercurializing to assist adhesion, see § 746.

814. *Striking the Objects.*—This term is used for the production of the first film; this, especially with the baser metals, usually requires greater E M F than ordinary working, but not too large a current. The way to effect this is to employ a high E M F with only a small anode, on the principles described § 796. The E M F must not be such as to give off gas.

815. In any case, after the first deposit is perfected, the object ought to be removed, washed, and well scratch-brushed, to see that the deposit is perfectly adherent, as it is less unpleasant to strip it and start afresh then (if necessary), than after the whole operation is supposed to be completed. When a thick coat is to be put on, and especially if there are ornamental edges and points, it is well to examine now and then, and if any nodules or roughnesses are forming, to file or work them off, perfectly cleaning the article before replacing. Objects should on no account be touched with the dry hand, but kept under water containing a little soda or potash, and handled only with perfectly clean hands.

816. DISCONNECTED OBJECTS.—An interesting experiment will illustrate the precautions necessary to observe with objects, and

also that peculiar state of the liquid which is called *polarization*, and which is the primary condition of electric transmission. Suspend two plates, connected with a battery, as far apart as the vessel allows, or, say 6 inches or 8 inches; in the centre of two plates of copper, an inch or so square, punch holes, and rivet them firmly on the ends of a stout wire. Now suspend this arrangement in the liquid between the plates, but not touching either, and having no metallic connection with the battery, but isolated in the liquid. After a little time it will be found that the end facing the anode is well coated with deposited metal, while the other end has evidently been dissolved; the intermediate wire will share these two conditions up to the middle, but the principal action will be on the ends. The system has been, in fact, polarized in the same manner as cylinders are, in static electricity, when approached to a conductor, and the action is distributed in exactly the same way as a static charge would have been, in the opposite ratio to the resistance between each particle and the conductor. This shows that objects should never be left in the solution when not being deposited on; if an object accidentally falls from its wire, it should be at once removed and rearranged, for if left, this effect will be produced upon it.

The effect is not well observed in a silver solution, owing to the chemical action of the copper itself, and it requires a strong current; in a copper solution the action is strikingly visible after a few minutes.

817. Anodes.—These should be sheets of pure silver, around the tank; or in small vessels strips of various sizes may be used, so as to be distributed about the objects as required. They should not be attached to copper wire, which is acted upon, though it is greatly protected by a thick coat of solder over it; they should be soldered to stout iron wire, or to strips of lead, which the solution does not act on, and these should have strips of copper, well silvered or gilt at their upper parts, for slinging upon the connections to the battery.

If the anodes become coated with a greyish coating, the solution wants more cyanide. When common silver is used, the anodes in this case turn red or purple, owing to cyanides of copper, &c., forming; but pure silver should be used, so as not to keep adding copper to the solution. The appearance of the anodes is the best indicator of the state of the solution: if too bright, there is probably too much cyanide; the happy medium is a clear chalky appearance, and it is far wiser to attend to the earliest indications of the anodes than to wait till the objects take their turn at complaining, which may mean spoilt work.

Arcas Plating.—This lately-introduced process claims to produce a non-porous and non-tarnishable coating of silver, harder than usual. It consists in the use of anodes containing a portion of zinc, and probably the addition of zinc cyanide to the solution.

818. WORKING THE SOLUTION.—A new solution does not work so well as one in constant use. The carbonic acid of the air acts upon the cyanide of potassium, which therefore requires to be occasionally added; the need for this is indicated when the action becomes sluggish, or the anodes and objects become discoloured. If the objects alone are dark and dirty in appearance, instead of clear chalk white or rich cream colour, the current is too strong, and the anodes should be reduced in size or placed farther away from the particular object, or, if the fault is general, the power may be reduced. Experience alone can teach all these details. The temperature should be the average one of 60° to 70° Fahr.; when it is colder, the solutions do not work so well, and, if hotter, less power will be required.

After a time, a precipitate usually forms as a greyish white flocculent powder, which is easily stirred up, and apt to settle on the articles, the solution should therefore be occasionally filtered. The precipitate is mainly impurity, but in some cases it may contain silver, so that it is as well to collect it, and when worth while, burn it in a crucible, with a little nitrate of potash added.

819. BRIGHT DEPOSIT.—Silver from the solution described is deposited of a beautiful dead white or "mat," but it may be deposited with a brilliant surface, as if burnished, by adding bisulphide of carbon to the solution. About an ounce of this is shaken up in a bottle with a pint of strong solution of cyanide of silver, and plenty of free cyanide. This is added occasionally as required, little by little, to the bath. It should not be used on the small scale, as it is offensive and unwholesome; excepting when in regular use, it is also apt to spoil the solution. The bright solution is usually only used to finish articles in, as it does not work so satisfactorily as the other.

820. FINISHING THE WORK.—On removal, the object should first be dipped in water containing free cyanide, then rinsed in boiling water, allowed to dry, and placed in sawdust (box or mahogany, not pine). All parts intended to be bright should then be scratch-brushed, either by the lathe or by small hand-brushes. After this, the surface should be polished with tripoli or rotten-stone, and whiting and rouge, and then burnished with brightly polished steel or agate burnishers, which are made of various shapes to suit different work; the object should be kept wet with soap-suds while burnishing, or some use stale ale.

This is an operation requiring much practice to do it well, and it is in fact a special business. Care should be taken to make the strokes of the burnisher always in the same direction, or only slightly deviating from it where markings require burnishing down; the strokes should never be crossed.

821. SPOILT SOLUTIONS.—From various causes, and chiefly from the gradual accumulation of the salts of potash, resulting from the action of the air upon the free cyanide, the solutions in time become bad; they do not deposit metal of good colour, or the deposit tends to strip under the burnisher. It then becomes necessary to recover the metal and make fresh solution. Two processes are commonly recommended: (1) To add acid until all the metal is thrown down, and then melt the precipitate after drying; this process is a dangerous one, and must be effected in the open air, as poisonous gases, chiefly prussic acid, are given off. The residue must also be fused by degrees, as the cyanide of silver does not fuse quietly; it is better to reduce it with zinc and a little hydrochloric acid—this also in the open air. (2) Evaporate the solution to dryness and fuse till the silver is reduced, and wash off the cyanide of potassium, which generally carries some of the silver with it.

822. The plan I recommend has the advantage of economy of materials, and freedom from danger or nuisance. Place the solution in a large flask, fitted with a safety funnel and delivery tube joined by an indiarubber pipe to a wide glass tube, the end of which dips half an inch into a solution of silver nitrate in another vessel. Now add sulphuric acid gradually by the safety funnel, allowing the effervescence to subside, and shaking the flask occasionally; continue adding acid as long as it produces any fresh precipitate. Then by means of a sand-bath, heat the flask and keep the solution boiling as long as a precipitate continues to form in the other vessel. The precipitate is pure cyanide of silver, and only needs dissolving in cyanide of potassium to form the fresh solution. The precipitate in the flask is also cyanide of silver, but not pure, though sufficiently so for use in most cases; if it is preferred it can be reduced by zinc and hydrochloric acid, or dried and fused. This process saves the cyanide of potassium otherwise required to precipitate the silver.

823. GILDING SOLUTION.—There are many formulæ given for dissolving chloride, oxide, or fulminate of gold in cyanide of potassium. These are all troublesome, expensive, and the last dangerous. The best plan is to dissolve cyanide of gold in cyanide of potassium. The strength should be from half to one ounce of gold per gallon, and it may be prepared by the

direct process, as described for silver § 702, but with gold it requires heat. It is, however, better to prepare the cyanide chemically. Pure fine gold should be used, but it may be obtained from any alloy by dissolving in aqua regia (1 part nitric and 3 of hydrochloric acid), pouring off the clear liquid and washings of any residue, evaporating off free acid, and precipitating the gold by protosulphate of iron (green vitriol or copperas), of which about five times the weight of the gold should be used. The gold is found (after standing an hour or two) perfectly pure as a dark brown powder. This, or "fine" sheet gold, is to be dissolved in aqua regia as before, and free acid driven off, care being taken that no yellow powder is formed; if it is, by too much heat, a drop or two of acid must be added to redissolve it. This solution should be largely diluted, and cyanide of potassium added as long as any precipitate is formed. This is the cyanide, a lemon-yellow powder, which only requires to be separated from the solution, washed, and dissolved in cyanide of potassium. These are the usual instructions, but I advise a little further proceeding, to avoid any risk of loss of gold by not hitting the exact point of precipitation. Add a trifle too much cyanide of potassium so as to insure complete conversion and redissolving of a little. Filter off the cyanide formed, and to the solution add sulphuric acid till it gives an acid reaction, and filter off after standing for some hours. Even then there is a risk of the alkaline salts dissolving some little gold, but this may be recovered by setting the solution aside with some scraps of zinc, which will throw down any gold so dissolved.

In dissolving common gold there is often found a residue which obstinately resists solution, yet retains the form and workmanship of the original article; this is the silver of the alloy formed into a dense chloride.

The chloride of gold solution may, if preferred, be neutralized with caustic soda or potash (not carbonate) until it is decidedly alkaline, and then either cyanide of potassium may be added, or hydrocyanic acid distilled into it to throw down the cyanide of gold. This solution is, however, very apt to retain gold in solution with the residuary alkaline salts. If ammonia is used instead of the fixed alkalies, a precipitate is formed, which is fulminate of gold, and must not be dried, as it becomes violently explosive.

824. SPOILT SOLUTIONS.—These should be treated as described for silver, § 821, but the resulting cyanide, which will probably contain other metals, should be dried, mixed with its weight of litharge, and fused. The residue, after washing, is placed in

excess of nitric acid, which will dissolve out the lead, &c., and leave the gold pure.

825. GILDING.—This process is much more rapid than any of the others, as a few minutes is usually enough to give a good deposit; this is due to the high equivalent, 197, so that the same current deposits nearly twice as much as it would of silver, and more than six times as much as it would of copper. Gold has also very great covering properties, and a much thinner film gives a better appearance and protection than a similar thickness of other metals would. The usual difficulty indeed is that the work is done too fast. Small battery power is needed, a single Smee having sufficient force for small articles: but with large surfaces, and especially when a deep colour is desired, two Groves may be used; the point to be aimed at is to have the E M F just below the point at which gas appears on the objects.

Small objects may be gilt together in numbers by putting into an earthenware basket with a connecting wire to some of them, and shaking about in the solution, so as to expose fresh surfaces continually.

826. HEAT IN GILDING.—The solution is to be heated in a glass or enamelled iron vessel to 130°–180° Fahr. The warmer the solution, the darker the colour of the gold, which is to be controlled by regulating the battery power and the heat. The anode should have the same surface as the object, and should be fine gold; the object should be kept in constant motion, and if the colour is too dark, its distance from the anode increased.

Gilding is one of the most difficult processes to teach; its variations are so great that only personal experience can be relied on, as the colour will pass from pale to dark with very slight changes in the heat, or with different degrees of motion.

When the solution is to be set aside, water should be added to replace that evaporated off by the heat; and the free cyanide, if needed, should be added at the same time.

826A. TINTED GILDING.—The colour varies from pale yellow to a deep tone, according to the heat, density of current, &c.; but definite tints are also produced for purposes of ornamentation, by variations in the solution.

Green gold deposit is produced by adding cyanide of silver to the solution, or working it from a silver anode till the desired tint is obtained.

Red gold is obtained in the same way by the use of copper.

In working these solutions, anodes of alloys of the proper quality should be used, or separate anodes as in § 686. Various tints may be obtained by adjusting the proportions, or even by shifting the articles from one solution to another, and allowing a mere blush of deposit to form in each: these being slightly transparent, various colour effects may be obtained, though they will not be very permanent.

827. *The strength of the solution* varies greatly under work, owing to the actions referred to § 789, and to the fact that cyanide of potassium dissolves gold pretty freely while hot; therefore, in addition to the solvent action of the current on the anode there is this direct chemical action on both anode and the deposited gold. Therefore the deposit may at times represent little more than three-fourths of the gold taken from the anode, while the solution tends to be enriched and the free cyanide to be used up. This, however, is met by using smaller anodes, and the usual tendency in working is to impoverish the solution by economizing the costly anode.

The *colour of the anode* is a very sensitive test of the state of the solution, and immediately shows whether the free cyanide is deficient, by becoming foxy; on the other hand, it ought not to become bright, but be of a clear dead yellow.

828. *Finishing* is effected precisely as described for silver.

Colouring.—If the colour is bad it may be made rich by the following mixture: One part each of alum, sulphate of zinc, and common salt, and two parts of saltpetre are mixed in water into a paste, which is to be smeared over the articles, which are then placed on an iron plate upon a clear fire, heated, and thrown into cold water. A bad colour in silver may be remedied with borax applied and similarly treated till it fuses. Articles united with soft solder cannot be treated by these processes.

829. PLATING IRON AND STEEL.—For some reason, difficult to understand, it is impossible to obtain an adherent coating of either silver or gold directly upon iron or steel, no matter how perfectly the surface may have been cleaned. It is therefore customary to deposit first a mere film of copper from an alkaline solution, as previously described. A film of mercury would have advantages over that of copper, for the same reasons that such a film is frequently used upon even copper or brass, to secure a more perfect union between the metals. But iron resists union with mercury as well as with silver and gold, and it is very difficult to coat its surface with a perfectly even homogeneous amalgam, though many processes have been suggested and said to be successful. That which I have found best consists of a mixture in equivalent proportions of the nitrates of silver and mercury, in quantities represented by about 50 gr. of each metal to a pint of solution. The metals are to be separately

dissolved in just sufficient nitric acid, the mercury in dilute and cold acid, and then mixed, sufficient free nitric acid being kept in the solution to feebly act upon iron when plunged in it. The metal leaves this solution covered with a dark powder, which, on lightly brushing under water, gives place to a bright surface. The object should be at once placed in the silvering solution, and, when a coating is seen to be formed, it should be removed, washed, dried, and heated to about 400° Fahr.: its surface should be then scratch-brushed, and the article replaced in the silvering solution till a sufficient coating has been deposited. Iron and steel may also be amalgamated by rubbing with sodium amalgam after well cleaning, and may then be plated in the same way as other metals.

830. NICKEL PLATING.—This process has come into much use in the last few years, and bids fair to be very largely employed for many articles in common use. There is, however, much misconception as to the purpose and advantages of a coat of nickel. It takes a very brilliant polish of a bluish tint, and the hardness of the metal enables it to retain that polish much longer than silver does; then, unlike silver, it is not affected by sulphuretted hydrogen, and does not blacken with the gases given off from burning coal or gas; it is therefore admirably adapted for such purposes as shop-fittings, and particularly scales and weights, which would merely require to be washed or wiped in order to keep them clean; and for window-frames and doors-plates, which would long retain their beauty with little labour. But it is often stated that nickel resists acids, and this is not the case, for all the ordinary acids dissolve it freely; it is therefore not suited for instruments to be used in chemical laboratories, or where acid fumes prevail; nor is it adapted for lining to vessels used for cookery, as silver is. However, although nickel is very closely allied to iron in its chemical properties, it does not rust in the air, though it takes a yellow tarnish, which may, however, often be due to an action on the underlying metal through the pores of the coating.

831. *Nickel Solution.*—Nickel may be deposited from almost any of its solutions, but compounds of the metal with alkalies work better than the plain salts of nickel. The *cyanide of nickel* and potassium works well, and is said to be improved by the addition of common salt. The *chloride of nickel and ammonium* is also a good solution, and may be made by passing a current from a nickel anode into a strong solution of ammonium chloride, as described for silver, § 702. The compound of nickel and ammonia with sulphuric acid is, however, the best, and it has two forms.

The *ammonio sulphate* may be prepared by dissolving crystals of nickel sulphate in liquid ammonia, forming a dark blue solution; it cannot be recommended, because it constantly loses ammonia. The sulphate of nickel forms $NiSO_4 + 7H_2O$ $155 + 126 = 281$, green rhombic prisms containing 7 atoms of water. Sulphate of ammonia $(NH_4)_2 SO_4 = 132$ has the property of replacing one of these atoms of water and forming the double crystal $NiSO_4 (NH_4)_2 SO_4 + 6H_2O = 395$, a saturated solution of which, with a little water added, to diminish the tendency to crystallize, is the solution to be used. Eight ounces to the gallon, making a solution of sp. gr. 1·06 at 60° Fahr. is found to work well.

The sulphate can be made by dissolving crude nickel in the acid, and purifying it from other metals, such as iron and copper. The double salt crystallizes out on addition of sulphate of ammonia in excess to the sulphate of nickel, as the double sulphate, though freely soluble in water, is insoluble in the sulphate of ammonia solution, which will, therefore, throw it down out of old solutions if desired. As the double salt is an article of commerce, it is better bought than made.

832. A solution which is said to give adherent, white, and soft deposits is made of—

Sulphate of nickel	1 lb.
Neutral tartrate of ammonia	11·6 ounces.
Tannic acid in ether solution	·8 „
Water	16 pints.

I have not tried it, but tartaric acid certainly has some valuable actions. The addition of borax or boracic acid to the solution, introduced by Weston, is considered to diminish the tendency to give off hydrogen.

833. Bright Nickeling.—Mr. Warren says, in the *Chemical News*, that trying bisulphide of carbon as with silver, he got a black deposit which could not be polished; but on using a *very little* he obtained brilliant coatings which needed no burnishing. He shook together in a bottle a gallon of the plating liquid and 1 oz. of bisulphide, allowing to settle, and adding 1 pint to 100 gallons of the working solution.

834. The *anodes* are made in both cast and rolled metal; the cast ones are to be preferred. Nickel melts easily, especially if a little tin or phosphorus is added. About 6 inches square of anode surface is used per gallon of solution, and the anode surface is always kept in excess of that to be plated.

835. *Depositing cells or vats* may be made of wood bolted together at the ends and coated with asphaltum cement. But it is better to use wooden casings lined with 6 lb. sheet lead, the

joints of which must not be soldered but *burnt* with the blowpipe: there should also be a lining of thin matchboards to prevent accidental contacts with the lead.)

836. Depositing Nickel.—The real difficulty lies, not in the selection of a solution, but in the management of the operation, for nickel is different from any of the ordinary metals hitherto described, in that its deposit is always accompanied by a considerable evolution of hydrogen gas; this is, of course, pure waste of power, and the object to be aimed at is to get as little gas and as much nickel as possible. Another consequence is, that the deposit is apt to contain gas, and therefore to be porous or flaky, in which case the coating tends (as soon as it reaches a moderate thickness) to split and curl up, and separate in brilliant films. To prevent this, the solution should be strong, and the power carefully adjusted to the work doing. A high E M F, 5 or 6 volts, is needed for the "striking," § 796, but in the working from ·5 to 1 volt is sufficient, according to the conditions.

The resistance of the depositing cell must be controlled by means of ample anode surface, fully as large as the objects. The solution must be kept neutral or very slightly alkaline by addition of ammonia when necessary, this being the most essential detail of the process: the tendency of all ammoniacal salts is to become acid by losing ammonia, and any free acid thus produced prevents metal from depositing, or redissolves it in the act of depositing, giving off hydrogen in its place.

The surface of the nickel deposit, when good, presents a very peculiar appearance; it is not bright—a bright deposit will usually peel off—but of a dull yellowish colour; after removal and washing it has to be worked up to brightness by the usual processes of polishing. Motion is a great advantage in nickeling.

837. Iron Depositing.—Iron has very great chemical resemblances to nickel, and most of the remarks made upon the latter metal apply also to iron. The solutions are corresponding ones, in which iron takes the place of nickel, but owing to the tendency of iron salts to pass into a higher state of oxidation, they spoil rapidly. Hydrogen is given off also, and it would appear that the corresponding oxygen appears at the anode, unites there with the iron, and thus tends to the production of basic salts. Many solutions have been tried, and the student will find an elaborate series of experiments by Mr. A. Watt, in vol. 47 of the *Electrician*. No deposit can be obtained from a solution of a ferric salt; in these the action takes the form of a generation of hydrogen at the cathode, which reduces the salt to the ferrous condition; at the anode, meanwhile, iron is

dissolved by the acid set free until a neutral ferrous solution is produced. In consequence of this, an iron solution which is spoilt either by action of the air or by generation of basic salts may be renovated by adding the proper acid, and, if needed, heating it till it becomes clear, and passing current from an iron anode. Mr. Watt asserts that ferric salts will deposit, though not satisfactory: but I think he has not taken account of what occurs. The action just stated will occur directly current passes, and the film of liquid in contact with the cathode at once becomes a ferrous salt, and from *this*, not from the ferric *solution*, he got what iron was deposited.

838. The solution which is found best is (as with nickel) the ammonio-sulphate of iron, obtained by dissolving equivalent proportions of sulphate of iron (green vitriol or copperas) 139 parts, and sulphate of ammonia 61 parts: it can be obtained ready crystallized, as it is used in photography, but is made more cheaply. A good working solution may also be made by passing current from an iron anode into a solution of 1 part sal-ammoniac in 10 of water.

It is considered that the addition of ammonia salts of organic acids, tartaric, acetic, and especially citric acid, improves the solutions, and I have found that the addition of a proportion of glycerine to the solution diminishes its tendency to spoil.

839. The *working* is much like that of nickel, except for the tendency of ferrous salts to oxydize into ferric salts, especially if there is any free acid present. Gas is always given off, and it is found that strong solutions do not work well. The anodes should be about the same area as the cathode, and the solution be kept neutral or slightly ammoniacal.

840. The deposit of iron is likely to have scientific uses, as in examining the laws of magnetism, but not extensive practical application. Its principal utility is likely to be in the same direction in which it has been used for some years—viz. for printing purposes. It has been used to give what is called a "steel face" to copper plates, by depositing on them a thin film of hard crystalline iron which does not seriously affect the fine lines of engraving, but wears much longer than copper, and when defaced can be dissolved by acids and renewed, without the plate itself being subjected to wear. It takes the ink well also, and will work with some inks, such as vermilion, which are useless with copper. It would probably answer well, also, for facing to ordinary type.

841. PLATINUM.—This is an exceedingly difficult metal to deposit, that is, as "reguline" metal; it is easy enough to get as a black powder. The deposit is crystalline and brittle; but

it is said that good non-porous coatings are to be obtained now, which, however, I will not maintain. The great drawback is that no solution acts on the anode: the platinum, therefore, is wholly derived from the solution, and must be replaced as chloride; this non-action of chlorine, even nascent, and in the electric circuit, is very difficult to understand, because platinum is chemically dissolved by chlorine, which unites with it readily as salts. A small "current," or rather small density of current, is required, in order to prevent undue generation of gas and black deposit. I have found that a "density" of 5 ampere-feet § 777, is the utmost current to be used, with a voltage of 2·5, to overcome the resistance of the solutions.

842. It may be noted that some metals are more difficult to coat than others, and that a preliminary coat of silver (a mere blush) will facilitate deposit. The objects ought to be thoroughly polished first, as the smooth surface does not free gas so readily. The current equivalent varies. I have obtained 44 to 48, the theoretical value being 49·3 = 1 of H.

843. Platinic chloride, $PtCl_2$ on the equivalent notation, or $PtCl_4$ on the atomic, is the basis of all the solutions of platinum. Its preparation requires some precautions, as it must not be heated at any time beyond the heat of the water-bath, or a change takes place which is not correctly stated in the text-books. They say that platinous chloride is produced, which will redissolve in excess of acid. I have found that over-heating, even with great excess of acid, turns the solution a dark olive instead of clear yellow (or red if iridium is present), and that a black powder is formed which cannot be redissolved without drying and heating to red: it may be that this is due to the other metals usually accompanying platinum. Platinum left in a bottle with aqua regia (1 nitric and 3 hydrochloric acid) will dissolve in time, but the process is a very long one; heating in a water-bath hastens it; it should then be evaporated to dryness in the bath, dissolved in a little water, and if desired left to crystallize. This solution may be used to deposit from, but it requires very great care.

844. *Sodio platinic chloride* is obtained by adding 1 equivalent of common salt (58·5) to 1 equivalent of platinic chloride (169·5), which corresponds to 98·5 of platinum in solution: it may be crystallized as a yellow salt. This deposits more easily than the chloride.

845. A still better solution is made by adding to the foregoing about 4 equivalents (63 × 4 = 252) of oxalic acid, and then rendering the solution strongly alkaline with caustic soda. This, in fact, is the best solution I have tried. A similar one

may be made from the yellow precipitate formed by ammonium or potassium chloride with platinic chloride. These precipitates are soluble in oxalic acid (a fact not noticed in the text-books, so far as I know, or in Storer's 'Dictionary of Solubilities'); more of the acid is required, however, and the ammonia precipitate requires boiling. The sodium form is, however, preferable, as most stable.

846. *Bœttger* says, that with fresh ammonio platinum chloride dissolved in concentrated solution of citrate of soda, forming a deep orange solution very rich in platinum, two Bunsen's cells give a lustrous homogeneous deposit.

847. *Roseleur* recommends 10 parts of platinum converted into platinic chloride, dissolved in 500 parts water; 100 parts crystallized phosphate of ammonia in 500 parts water; these two being stirred together a precipitate is formed: 500 parts of crystallized phosphate of soda dissolved in 1000 of water are now added and the whole boiled as long as ammonia is given off, and until the liquid has an acid reaction. The solution is to be used hot, with a strong battery.

848. *Wahl's solution* is highly spoken of; it is based on *platinic hydrate*, which may be thus obtained: 1, heat a concentrated solution of the chloride with sulphuric acid, until dry; 2, dissolve the sulphate thus produced in water, precipitate with carbonate of lime, then wash with weak acetic acid to remove excess of lime salts, and with water: it is a brown powder, which decomposes if heated to the boiling point of water, and is freely soluble in most acids, and in alkalies, with which it acts the part of an acid. The *oxalate* is recommended as the best acid: 1 ounce of the hydrate to 4 ounces of oxalic acid in 1 gallon of distilled water.

The *alkaline solution* is made from hydrate 2 ounces, caustic potash or soda 8 ounces, water 1 gallon, using half the alkali in a quart of water to dissolve the hydrate with stirring, and then adding the rest: it requires a force of 2 volts and gives a silvery white coating upon copper or brass; there should be very little hydrogen given off at the cathode, but abundant oxygen at the anode. This metal is said to be softer than that from the oxalate solution.

849. *Wahl's anode treatment.* This appears to be very promising: the difficulty of non-solubility is very imperfectly met by adding salts of platinum, as this continually alters the solution, but *the addition of platinic hydrate* has no such effect, and may be adopted with any of the solutions described. In solutions with much free acid or alkali which dissolves the hydrate, it *must be* added occasionally to replace the platinum taken out of

the solution, but if the solution is neutral, or the free acid is *acetic*, which acts well and does not dissolve the hydrate, a carbon anode can be used in a porous bag containing the hydrate, which will then act a soluble platinum anode, or the hydrate can be simply hung in the solution and left to dissolve as free acid accumulates from the action.

850. *Iridium* can be treated in the same way, by the hydrate process, and in view of its great hardness there may be purposes for which it would be useful, notwithstanding its high price.

851. ALUMINIUM.—The depositing of this metal would be a process of great value in the arts. Several such have been published, and some patented, but none is of any practical value. In one case it is stated that a solution of alumina mixed with cyanide of potassium decomposes with six Bunsens or ten Smees. This statement is strictly true; it does decompose, only, unfortunately, it does not deposit aluminium, but simply gives off hydrogen. I spent a good deal of time and trouble over this, till I satisfied myself that cyanogen will not unite (as a cyanide) with aluminium. In another book (a good one, too) a process is given which is essentially one for obtaining a solution of sulphate or chloride of aluminium, and it is stated that from this a fine white deposit of aluminium can be obtained. It may be so, but all I can say is, I cannot obtain it, nor can I find that any one has as yet succeeded in effecting a deposit; all the solutions I have tried, acid, neutral, and alkaline, decompose and give off gas, but refuse to deposit metal. I leave this remark unchanged, as, though many new processes have been published and several patented, I do not learn that any results have made their appearance. I believe, however, that aluminium may be more readily deposited in alloy with other metals, and with great advantage.

That aluminium can be reduced from its fluoride and other combinations when in a state of fusion has long been known, and several of these processes are now the source of cheap and abundant production.

852. *Cowles' electrical furnace* is the best known, and though it is claimed that the high temperature to be produced electrically is the real agent, there can be no doubt that electrolysis, bringing into action the affinities of carbon for oxygen, has a great deal to do with the result. The furnace is internally heated by the electric arc generated by a large current between carbon electrodes; corundum Al_2O_3 is mixed with carbon, the best results being attained when copper also is present so as to produce an alloy. The furnace is fire-brick, through the ends of which sliding rods of carbon pass, which are gradually drawn out

as the heat generated permits the arc to be enlarged. After the charge is reduced, the furnace is allowed to cool, when the metal is found in a mass on the floor, which is made of powdered carbon.

853. *The Heroult process* makes the furnace itself one of the electrodes; it is made of iron, lined with powdered carbon and tar, which latter is burnt off in the usual process of carbon making, § 248; the anode of carbon slides through the top of this furnace or internally heated crucible; copper or other suitable metal is put in the bottom, and forms the real cathode, and the ore is put on this and melted by the arc formed: its oxygen unites with the carbon anode, which has therefore to be continuously moved forward. In this process the product is run off at intervals, and fresh charges run in without cooling the furnace.

854. Others reduce the fluoride of aluminium and sodium, cryolite, mixed with sodium chloride, the fuzing point of which is 675° C. M. Minet says this works with 5·5 volts and a density of 1 ampere per square centimetre of carbon anode.

Others use the fused cryolite, but only as a solvent for alumina, which is supplied as reduced. It is stated that carbon is consumed about equal in weight to the aluminium produced, and that 1 electrical H.P. is used per ½ lb. of metal.

855. *Lead and tin* may be deposited from their combination with potash, but it can rarely be worth doing; they both have a tendency to send out threads of metal across the solution.

Litharge boiled in caustic potash is probably the best for lead; but some use acetate or nitrate of lead. The principal use is for colouring, § 722.

White lead is also produced by a patent process from an anode of lead in a solution kept supplied with carbonic acid, and is said to be of excellent quality.

Stannate of potash can be prepared by boiling tin oxide in potash, and is used like the lead compound, some add pyrophosphate of soda and cyanide of potassium.

856. *Refining lead* is effected by electrolysis of the rough metal in a solution of lead sulphate in acetate of soda: iron and zinc accumulate in the solution; gold, silver, and antimony remain on the anodes from which they are brushed and reduced chemically; the lead is deposited nearly pure, and it is said at a less cost than by the ordinary processes.

857. *Refining copper* is similarly carried on upon a very large scale, and some attempts have been made to reduce ores by electrolysis. The process is the same as the ordinary one of deposition, but carried out on a large scale by large current giving *dynamo* machines, with a number of vats suitably arranged.

858. *Arrangement of vats.*—These, like cells of batteries §§ 173 and 530, are connected in series or in parallel as suited to the E M F available and the current required; this applies equally to large refineries, or to small works where deposits of different kinds are produced.

It is obvious that the dynamo must generate an E M F or voltage greater than any operation needs. If it is designed only for that force it is evident the vats or cells must all be in parallel to draw current from it, but if any operation needs only half the generated voltage, then two vats may be put in series.

So it may be economical to arrange the plant in such a way as to have from the machine a higher voltage, but less current than the work requires, and then use the current several times in vats in series, so many as the E M F permits. In this way other work, needing higher voltage (such as arc lighting), can be done in parallel from the machine.

But *vats in series need care;* work must not be removed from any one so as to cut off current from the whole series; it must be removed by small instalments, or else a spare vat should be provided and turned into the circuit, in place of one about to be emptied.

Dynamo machines for electrolytic work should always be made to give a constant E M F, no matter what current they may be called upon to give, large or small.

859. WASTE IN ACTION.—In actual working the various figures or results stated will never be realized: there are causes in operation which diminish the result, but these vary in each case and according to the care of the operator, who must therefore ascertain the " discount " applicable to his own work. Bad connections, or accidental contacts may send the current some other way than through the solution.

The *solvent always takes metal* from the deposit, making it appear less than it should be. The cyanide solutions always attack the deposit, especially when heated. But even copper in sulphate of copper is attacked; by an elaborate series of experiments Gore showed that a loss ranging from 1 per cent. up to even 18 in some heated solutions, occurs with copper salts. I do not consider that a loss of even ·5 per cent. should occur, but it depends on the purity of the salts and acids; any nitrates present would increase the loss.

Hydrogen given off, as with nickel, § 836, implies a deficiency of metal equivalent to it.

860. *Organic acids* have peculiar relations to metals, and their presence often brings about great modifications of chemical

actions. This has been found of service in electro-metallurgy and offers a prospect of many new ones.

Cast-iron and steel have been coated with copper on the large scale for many years, as for lamp-posts, statues, &c., by Weil's solution, which is made thus, 150 parts of Rochelle salt (tartrate of soda and potash) are dissolved in 1000 parts of water; 80 parts of soda-lime containing 50 or 60 per cent. of caustic soda, and 35 parts of sulphate of copper, are added. The lime removes the sulphuric acid and the solution remains a strongly alkaline one. This solution may be used with a battery, but is best worked by single cell process, either by attaching zinc to the objects or by using a porous vessel containing caustic soda for the zinc. As the copper is removed an equivalent proportion of oxide of copper should be added.

Similar solutions can be used with nickel and other metals, and other organic acids have similar effects; see § 832.

861. Depositing Alloys.—It is supposed by many, and the idea is supported by many indirect statements in the books, that metals deposited by electrolysis are absolutely pure; but this is a mistake, as far as the principle is concerned. It is true that the current exercises an elective influence when salts of several metals are in company, as explained, § 699; this depends upon the force that each chemical compound requires to break it up, and therefore, as a rule, the most easily decomposed will deposit its metal in preference to the others; but if the force be sufficient, all will be decomposed, and a mixture of metals will come down, § 685. The solution also exerts a selective influence on the materials of the anode; hence pure copper can be obtained in a solution of the sulphate from an impure plate, because the sulphuric acid refuses to dissolve the carbon, lead, tin, &c., which form a coating over the plate, while any zinc and iron passing into solution require so much more force to decompose that they remain in solution; but pure copper would not be so easily obtained from a solution of chloride, nitrate, or acetate, as these would carry over the easily reducible metals, which would deposit even before copper.

862. But the object in depositing alloys is to secure a definite proportion of a given quality, and as to the mode of effecting this little is really known. The subject is of so much interest, and may have so much importance, that I depart from my usual practice of stating nothing that I have not thoroughly tested. In this case I propose to give the particulars of various solutions for depositing brass and bronze, and then a statement of the principles to be attended to in any attempts to devise solutions and modes of working.

The quantities are proportional, grains or ounces, &c.:

BRASSING SOLUTION.

	1	2	3	4	5	6	7	8
Water	5000	5000	1280	50	400	160	10	2000
Copper	..	..	..	..	..	..	..	..
„ chloride	25	15	..	..	2	..	..	10
„ acetate	..	..	5	10	..	..	..	..
„ cyanide	..	..	..	..	..	2	..	..
Zinc sulphate	48	35	10	..	4	..	..	20
„ acetate	..	..	..	1	..	..	..	..
„ cyanide	..	..	..	..	..	1	..	..
Potassium cyanide ..	12	50	8	*	..	16	1	24
„ carbonate ..	610	500	72	..	50	..	..	160
„ acetate ..	..	..	..	10	..	..	..	..
Ammonia liquid ..	..	..	40	..	..	..	..	*
„ carbonate ..	..	..	..	..	..	16	1	..
„ nitrate ..	305	..	..	..	25	..	..	..

* Sufficient to effect the purpose.

1. De Salzede.—Dissolve the cyanide of potassium in 120 parts of the water, then in the remainder dissolve the salts of potash, zinc, copper, and ammonia, raising the heat to about 150° Fahr., adding each salt as the first is dissolved, and stirring well; then mix, and allow to stand a few days.

2. De Salzede, prepared in same way as 1.

Both are worked with brass anode, and a battery of two Bunsen's cells giving a full current.

Bronze may be deposited by substituting chloride of tin for the sulphate of zinc—25 parts in 1, and 12 in 2, working at a temperature not exceeding 97°.

3. Divide the water into two parts, and one of these into four parts, and dissolve the salts. 1, the copper, and add half the ammonia; 2, the zinc, at about 180° Fahr., and the rest of the ammonia; 3, the potash; 4, the cyanide of potassium in hot water. Then mix 1 and 2, and add 3 and then 4, stirring well; then add the remaining half of the water.

Work with brass anode and full battery power, adding ammonia and cyanide of potassium when required.

4. Russell and Woolrich.—Dissolve the salts, and add sufficient cyanide of potassium to redissolve the precipitate formed and be somewhat in excess. Worked with brass anode.

5. Dissolve separately and mix.

6. Dissolve and mix, adding the cyanide last.

7. This is to be prepared by the battery process, the solution being made and worked at 150°. A large brass anode and a small cathode are connected to a battery, and current passed till the solution deposits freely.

8. Brunell.—Dissolve separately, mix the copper and zinc solutions, each with part of the potash, then with ammonia enough to redissolve all precipitate, and add the cyanide solution. To be worked with large brass anode and two or more Bunsen's cells, adding ammonia and cyanide as required.

It is stated by Watt that the solutions 3, 7, and 8, containing ammonia, work the best, because they dissolve the zinc from the anode more freely; and that whenever a white deposit forms on the anode, free ammonia should be added.

No. 6, which is Morris and Johnson's is spoken of very highly by some as giving good deposits capable of varying proportions. It is to be worked hot, and requires strong battery power, giving off abundant gas while working.

Weil's solution, § 860, can be used to deposit bronze by adding stannate of soda, or chloride of tin dissolved in caustic soda; or brass by a similar addition of zinc dissolved by caustic soda, and so on with other metals as desired.

863. *Principles.*—(1) The object to be attained is the deposit of definite proportionate weights of two or more metals; but as the current knows nothing about weights, but measures its work by equivalents, the proportions by weight desired must be reduced to equivalent proportions, by dividing the weight by the electric equivalent given in the table, p. 308. Thus, a brass is required containing 64 copper to 36 zinc; $64 \div 31{\cdot}75 = 2{\cdot}02$ and $36 \div 32{\cdot}6 = 1{\cdot}08$ gives the proportion in which the current must divide itself between the salts of copper and zinc.

(2) The solution need not contain the two metals in either of the two proportions, weight, or equivalent; the relative degree can have no fixed law, as it must depend on several conditions, and mainly upon a combined consideration of the facility with which the two salts decompose, and the equivalent proportion required to be decomposed.

(3) Incompatible salts cannot be joined in one solution (that is to say, salts which exchange their constituents or throw down a portion as insoluble), unless another ingredient is to be added, which will redissolve the precipitate; this latter is often the case when ammonia or cyanide of potassium is to be added, more especially ammonia. In such cases, however, it must be ascertained that these new conditions do not alter the relative conductivity or decomposability of the various metals in solution.

(4) It is of the utmost importance that the metals of which the alloy consists should not have any strong electric relations to each other in the solution to be used. It must be remembered that what is called the electric order of metals is a pure delusion, unless taken in a particular solution, for a metal may be positive to another metal in one solution and negative to it in another, as this depends on the relative affinities of the metals to the other radicals, § 605.

(5) It is *desirable* that the several salts should have nearly the same electric resistance, or that these resistances (which partly depend on the quantity of each salt dissolved) should be proportioned to the relative currents required (see 1); but this is not essential.

(6) It is *essential* that the battery power be balanced against the decomposability of the several salts. This is distinct from their resistance. Each chemical combination needs a fixed force to decompose it, and this is effected by maintaining a sufficient electric tension at the plates to effect it. This may be called the *specific molecular resistance*, set up at the cathode only, while the electric resistance lies in the space between the plates. If there is a great difference between the specific molecular resistance of the different salts, the current will tend to reduce the lowest only, and that perhaps in a powdery state; in such cases the only remedy is to have only a sufficiency of the weaker salt present to supply the required deposit, thus forcing the current to act sufficiently upon the more resisting salt. See § 699.

864. PRACTICAL SUGGESTIONS.—There is only one mode of satisfactorily examining all these points, and this is to test each one by means of a galvanometer which will measure the actions on a definite system. Vessels of the same size should be used for comparing different solutions, and plates of the different metals and also of the desired alloy provided, all of exactly the same size, such as a square inch or 1 × 2, with such an arrangement as will insure always the same distance between them; then, to ascertain if the condition 4 is fulfilled, the two metals are connected to the galvanometer as if they were battery-plates, to see if a current of notable amount is set up. The same arrangement tests condition 5 by using two plates of the same metal as the solution; the greater the resistance, the less current will pass from a constant battery. Condition 6 can be tested at the same time by observing how many cells of the battery are required to force a given current through, but this test will be only approximate, as the resistance affects it; still, it will give practical information.

Care must be taken that there is sufficient free solvent and also water to freely dissolve the anode and keep it clean, as sometimes one metal will dissolve more readily than the other. This, as well as other points, will be ascertained in the experimental vessel by testing with separate anodes of the various metals; they ought all to allow the same current to pass under the same conditions, because this depends wholly on the action of the anode.

It will be observed that the object in these experiments is to isolate and vary one particular fact at a time and measure its influence.

865. Anodes.—These should usually be of the kind to be deposited, so as to maintain the solution uniform. But it may be desirable to use several plates of the separate metals. Here, I think, may be found a principle in alloy depositing which has not yet been employed—viz. to use a separate battery for each anode, so as to vary the force exerted on each metal as necessary; by this means both conditions may be controlled, exactly the proper proportions of each metal may be forced into the solution, and the required tension may be exerted upon each. It is true that the metals are not transferred by the current itself, and therefore the different currents will not select at the cathode their own particular metal, but a sufficient electric force for each will be present at the cathode, and the due utilizing of it must be provided for by attention to the other conditions explained. A similar result may be attained with one battery sufficiently powerful, by leading separate connections from the positive pole to each anode, and interposing resistances so as to control the current to each; but distinct batteries would be best. Of course, all the negative poles would go to the object to be deposited on the cathode; it would also be desirable to have a galvanometer in the circuit of each anode to secure accuracy.

In a paper by Mr. G. C. V. Holmes on the Modern Applications of Electricity to Metallurgy, 15th January, 1892, the general law of electrolysis, § 684, is stated to have been first published by Dr. Kiliani of Munich, in 1885. It was really first published by myself in the *English Mechanic*, vol. xx. p. 2, 18th September, 1874.

CHAPTER XI.

TERRESTRIAL ELECTRICITY.

866. Earth Currents.—The telegraph lines have revealed the existence of currents due to causes independent of the batteries, varying in direction and also in strength; they frequently render it impossible to send messages along lines by means of the usual earth plates, but necessitate a return wire circuit, proving that the E M F exists at the earth plates, not in the wires. It has also been found that lines having east and west direction are more disturbed than those having a north and south direction. It is not necessary to go fully into this subject, as to which knowledge is imperfect, though growing, but the following particulars are derived from various communications to the Institution of Electrical Engineers.

867. The usual effect of the earth currents is that of a low E M F continually fluctuating in intensity while nearly constant in direction, which may be considered the *normal* action; there are, however, reversals of direction of the *current*, though it seldom changes its line of conduction; and at times there are great and rapid changes, both of force and direction, which are called *magnetic storms.*

868. *A general cause produces the currents;* they are not due to local conditions at the two points connected by the wires, for a comparison of observations taken at many different parts shows simultaneous variations.

869. The general *direction of the currents*, that is to say, their course, appears to be along the lines of magnetic latitude, those of equal declination, or north-east and south-west in England; this of course must be the case if the currents and the earth's magnetism are in any way connected together. Eliminating the various disturbing causes, it would appear that the proper direction, that is, the *normal current, follows the sun:* that is to say, it corresponds with Fig. 29, p. 86, and with Fig. 31, constituting the earth a magnet with its south pole pointing north, which is really the case if we compare the earth with one of our magnets.

870. The E M F corresponding to the currents is usually

about volt ·03 per mile. During a general disturbance in January 1881, it rose to volt ·5 per mile, and at the same time an unusual disturbance occurred in the activity of the sun; in other cases a force of 2 volts per mile has been observed, and it is said to have risen as high as 6 volts.

The E M F shown in submarine cables is much lower than that of land lines, rarely exceeding 1 or 2 volts for the whole cable; but it does not follow from this that it is really lower in the ocean than in the earth. The resistance of the sea is practically nothing; the line in which the earth current is set up is really a mere derived circuit from the natural one; therefore the current traversing the conductor will of course be proportional to these resistances and must needs be lower in cables traversing the sea than in lines dividing with the earth.

871. The E M F has *periodic variations:* it has a *diurnal* variation, with maxima about 10 A.M. and 4 P.M., also after midnight, and a minimum near sunrise. Information on this point is scanty and not to be relied on, but it indicates a connection with the solar heat corresponding to the magnetic variation, § 349. It also shows that we must regard the earth's magnetism, not as consisting of one definite homogeneous line, such as would be due to a permanent bar magnet passing through the earth, or to one suspended within the earth's interior, but rather as due to a series of independent bars or lines forming a shell, each line of which has its own local influences and independent motions, besides combining to produce the total effect of the earth's magnetism.

872. *Magnetic storms* are also periodic and related to solar activity, the maxima and minima of frequency coinciding with the 11-year cycle of sun-spots, and special storms have often been found to occur in company with the outbreak of large spots on the sun; see § 158.

873. It would appear from observations of Mr. A. J. S. Adams that the *position of the moon* as regards the earth has some important influence upon the normal current, though we may not adopt all the theories on the subject which he examined in a paper published vol. x. p. 34, 'Journal of Society of Telegraphic Engineers' for 1881.

874. The *magnetic variations*, § 349, indicate that the presence and position of the sun is acting, and we have two modes of action to consider: 1. The thermo-electric; we have two points of growing and diminishing heat at opposite sides of the earth, and points of maximum and minimum heat between them, and these points travelling round the earth. 2. The magnetic:

variation of temperature modifies magnetic capacity and intensity, § 154; all the materials of the earth are magnetic, and therefore the heat of the sun must produce a state of lower magnetism travelling around the earth, with an electric current as a consequence. All these no doubt play their respective parts in the total effect.

875. As the magnetic polarity and intensity of the earth undergo constant changes at each locality, which are tantamount to moving a magnet across the normal earth currents, it follows that we must expect a variation in these currents themselves; but which is really the cause and which is effect we must wait to learn.

876. SUPPOSED STATIC CHARGES.—From observations taken at Kew and Greenwich it appears that no changes in the electrical conditions of the atmosphere are found to accompany the magnetic storms, a circumstance of great significance to any theories based upon supposed static charges on the earth.

The idea that static charges exist upon the bodies in space is a very favourite one with theorists who wish to explain comets' tails and other matters beyond our knowledge: they usually forget, however, that the very nature of electricity involves equal *opposite* charges, and would necessitate that in the solar system the sun must have a surface charge equal to the sum of the opposite charges upon all the planets.

877. COSMICAL ELECTRICITY.—It is natural enough to imagine that the mysterious and seemingly all-pervading force of electricity may play an important part in astronomical phenomena: there is, however, no warranty for the supposition, and when we consider that electricity is a purely molecular relation, there is good reason to believe that nothing resembling electrical or magnetic action occurs across space. That energy traverses space is, of course, certain, but in which of its forms it does so is unknown, though light appears the most probable. But there is no sort of evidence that anything resembling static electrical actions occurs, or that the cosmical bodies have anything in the nature of free charges of electricity.

There is much evidence that simultaneous actions occur upon the sun and the earth, § 872, but the common deduction that they are of the same nature has little foundation: it may be natural enough to imagine, when a sudden magnetic action occurs on the earth which is accompanied by an apparent action on the sun, that this solar action is of the same order, electric or magnetic, and that the connection across space is an action of these forces such as we observe in our experiments. But other equally valid explanations are available, because we know perfectly well that magnetic and electric phenomena do ordinarily arise from transmutations of energy: the heating of a junction of iron and German silver wires at once produces electric current, and will generate a magnet. A disturbance in the emission of energy from the sun may well produce magnetic actions on the earth though no magnetic action may occur in the sun itself, and no magnetic or electric field of force exist in space.

878. The nature of electricity itself is opposed to the idea, when we recognize that it involves two equal opposite charges connected by lines of force. Therefore, it is impossible to conceive all the bodies in space "charged with electricity of the same sign," as some have suggested, which would involve a mutual repulsion, according to the doctrines connected with supposed free charges. But we have positive proof that opposite charges do not exist on the sun and the several planets. *If such charges existed, gravitation would not be a constant force.* The planets, as they approached each other, would have their attractions partly neutralized by electric repulsion, and this effect would vary with the mass and size of the planets, because their capacity for electricity varies as their radius, § 107 (*a*), while their masses, if constituted alike, vary as the cube of the radius. But astronomy shows that the mutual action of gravitation is directly as the masses, and is the same between the several planets as it is between them and the sun, neither of which would be the case if they were charged bodies, as the sun would have the electric attraction added to that of gravitation, while the planets would repel each other against gravitation.

879. It is only right to mention that Dr. O. Lodge has said, in reply to this, that if the earth and sun are conceived as charged to a million million volts, they would only exert a force of 22 tons weight on each other. It may be so, but Professors Ayrton and Perry calculated that, taking the value of atmospheric potential estimated by Sir W. Thomson, § 891, "the probable *actual* charge equals 1364×10^{12} C.G.S. units or about 14 times as great as would be necessary to produce the earth's magnetic moment if the earth were solid iron," and that Professor Rowland arrived at very different conclusions, and even that the result would be that the moon would be driven off into space, and the earth be burst up altogether. Of course all these varying results are each demonstrated by elaborate mathematical calculations; however, it is difficult to understand how so small a force as Dr. Lodge suggests can disturb the magnetism of the whole earth and set up strong currents over its whole surface.

880. *Is the sun a magnet?* Even this is doubtful considering its temperature, and the known fact that magnetism disappears at a very moderate degree of heat.

Does the sun exert magnetic powers? This we can answer in the negative. All that we know of magnets proves that their fields are limited, and consist of *closed curves connecting their two poles.*

881. *Magnetism is not a radiant force:* the curves may extend to distances further than our experiments can determine: but our experiments are all conducted among surrounding matter. We may imagine that its lines may be propagated in the ether, but we know nothing about it: however, we do know that they are dual in direction, not radiant, but continuous within and around the mass of the magnet.

882. If the sun were a magnet exerting force upon that known magnet—the earth—the magnetic axis of the earth would place itself on one of the curves, as all magnets do; but the magnetic axis shifts its position in a definite period, § 147, while the axis of the earth itself does not vary in its relation to the sun.

But the N and S poles of the earth are continually altering in their presentation to the sun; if any magnetic force existed, the earth's axis would sway in space with the seasons: not even the persistence of motion, as shown by the gyroscope, would resist this steadily varying stress of changing position in a field of magnetic force.

883. *Clerk Maxwell's theory of light* is that light itself is an electro-magnetic disturbance: he conceives that electro-magnetic action is transmitted across space by waves at right angles to the line of transmission, as light is; that electricity and light have the same absolute velocity, and that as a consequence all true conductors of electricity are opaque, as to which see § 650. It is now steadily asserted by the hypothetical type of scientists that this theory has been proved by Hertz's experiments; it will be shown later on that these experiments bear an entirely different explanation, but such determined assertions by eminent men influence the minds of those who do not think for themselves.

884. Maxwell's theory has been entirely transformed, and what is now supported is quite a different matter. What Clerk Maxwell suggested was that radiant energy had a three-fold function, and he gave a diagram of it: his idea was that the rays undulating transversely to their line of propagation, the direct or linear action was *light*, the action in one plane at right angles was *electricity*, and in the other plane was *magnetic;* now this of necessity implies that the *vibrations of all are identical.*

885. But what is now taught is that all these are vibrations, but of *wholly different orders:* that slow undulations are electrical and magnetic, and rapid ones are light. What the Hertz experiments are alleged to prove is that electric and magnetic propagation is of the nature of undulation, and that therefore light and electro-magnetism are of the same order, differing only in rate, as do the undulations which produce heat and light. This may be true or false, but it is not what Clerk Maxwell meant.

886. But *is it true?* Is it not one of the most certain things within our knowledge that light and magnetism are essentially distinct? The certain fact that light is directly linear—a straight motion directed only from its source, while magnetism is always directed in a curve, and controlled at all points of its circuit—is an absolute contradiction to the idea of their similarity of nature.

Another clear proof that they have no identity of nature is the certain fact that radiant motion of light once set up, *nothing will divert* it, unless the rays fall on an object which can reflect or refract it: matter can do this, or it can extinguish the light altogether by absorption. But magnetic lines can be attracted out of their direction altogether by any matter which possesses higher capacity than the original medium, and yet nothing can absorb or extinguish them: the attracting agent can only transmit them, and constitute a more favourable circuit.

887. Neither Hertz nor any one else has given any evidence whatever that the propagation of electric or magnetic action or force is undulatory: they have produced successive impulses or disturbance in rythmic order, and it is these impulses to which their results relate; but any rythmic disturbance which grows gradually (as every disturbance does) is of necessity propagated as an undulation in the transmitting agent.

Let us conceive a church bell whose note is 16 undulations a second, struck at intervals of 15 seconds; we have now two orders of sound effects: both may be called *waves of sound*, but only one can be called *sound waves.* We have the continuous vibrations, the sound waves 16 to the second, whether weak or strong; and we have the sound of each stroke giving a wave, not of sound itself, but of strength of sound—waves, that is, not of propagation, but of rising amplitude. Hertz's experiments may have proved the undulatory nature of the transmission of the impulse of induction, magnetic or electric, the analogue, not of the notes *of* the bell, but of the strokes *on* the bell; but of the nature of the propagation of the forces, these experiments teach us nothing.

888. That there is a connection between light and electricity is certain from the effects of electric stress upon the transparency of substances and from the fact that the specific inductive capacity is related to the square of the index of refraction; this is a result of the theory which is approximately true for rays of great wave-length. But it may be doubted whether all the coincidences are not consequences of the molecular actions of both light and electricity upon matter, rather than evidences of identity of nature or action; if electrical action and propagation consist of rotations of molecules under the influence of a force transmitted from one to another in a line, it is clear that there must be points of resemblance and occasionally apparent relations to the motions or undulations which transmit the radiant forces. At present the theory is only a matter of speculation, but it may ultimately become of importance in connection with the transmission of energy across space, and for that reason it is considered here.

889. ATMOSPHERIC ELECTRICITY.—Inasmuch as every chemical action or even mechanical disturbance of molecular arrangements sets up electrical conditions, which very often are regarded as causes when they are mere consequences (as in the phenomena of life), we might expect to find the moving and changing atmosphere in a constantly varying electrical condition, varying in fact not only in time, but at even neighbouring places. We may also be certain that these changes must react upon the vital actions and sensations of all organisms influenced by them, and that the average electrical condition of any place will be an important element in its climatic qualities; but very little is as yet known on this subject.

890. The electric condition of any point in the atmosphere is observed by means of a conductor terminating at that point and brought to the same potential. This may be effected by means of living vegetables, such as grass and leaves, which are more effective than the pointed metallic conductor; it is more commonly effected by means of a flame or a roll of smouldering touch-paper at the end of the conductor—Sir W. Thomson uses a metallic cistern of water fitted with a tube from which the water continually drops. These conductors are insulated from the earth and connected to the electrometer, such as one of the pairs of the quadrant electrometer; the other pair being put to "earth" so as to indicate the "difference of potential" between the earth's surface and the point of the conductor. Greater elevations may be explored by means of kites, the string of which may contain a wire. It was by such means that Franklin established the identity of lightning and electricity.

but it is a dangerous experiment and more than one has lost his life in making it.

891. Sir W. Thomson found a difference of potential of 430 volts in 9 feet, or from 23 to 46 per foot, at the Isle of Arran, and 40 at Aberdeen. But we cannot legitimately deduce from this that a similar rate of increase extends to any great distance from the earth's surface.

The electrification varies, being at its highest about 8 A.M., and 8 to 9 P.M. in summer, and 10 A.M. and 6 P.M. in winter, and lowest about 3 P.M. and midnight: this really indicates that it is highest just when the greatest change of temperature occurs, and when the dew-fall and evaporation are greatest. It may interest some to know that an east wind always raises the + electrification while rain is almost always attended with − potential in the air.

892. Professor Palmieri finds that in Italy the condition is always + when neither rain nor snow or hail is falling within 150 kilometres; if − electricity is found with a clear sky, downfall at a little distance may be inferred. But Professor Mitchie Smith found that at Madras, with a dry land wind, the potential is − after 9 A.M. till the sea breeze sets in; these observations really coincide with those of the Italian observer, and they prove that atmospheric electricity is not a cosmical phenomenon; that it is not related to or originated from space inwards, but an action from the earth outwards and related to the outer layers of the atmosphere.

893. This electrification is in no sense a static charge; it is simply a condition set up in the air analogous to that which exists in the glass of a Leyden jar; the surface of the earth and the air have equal + and − electric quantities distributed over them, or inasmuch as there is really no "quantity" at all on the earth's surface (or, if it is considered as having a − charge its quantity varies with the thickness of the air compared with it), what is really measured is the energy stored in the "field of force" constituted by the air space: therefore there remains nothing to act towards external space.

894. It may be worthy of consideration whether a difference of *electric potential* exists at all in the atmosphere in ordinary conditions, or at all events whether more than a small portion of what is observed exists as such. It is most probable that a continually varying electrification is really produced by the friction of wind and of cloud masses; but it may be that the greater part of the observed effect is due to the instruments themselves; that the *charge* is potential energy, not electricity, and that the *conductor* of the instruments, by providing the return circuit,

establishes the conditions under which the potential energy takes the form of E M F.

895. *Evaporation* from the salt-containing waters of the earth has been commonly regarded as the source of atmospheric electricity, this act being supposed to carry off + electricity and so leave the earth itself – ; but the balance of evidence indicates that electricity is not developed by quiet evaporation. Those experiments which indicate its production are attended with other causes, such as chemical action upon the containing vessel, or else friction set up by rapidly issuing steam. Faraday examined this subject with his usual care, with the result that the electricity was due not to the evaporation, but to the friction of particles of water, &c., carried by the issuing steam; he also found that the addition of various substances modified the result, an action which is traceable to changes in the surfaces of the particles of water.

896. But it is most probable that although evaporation does not directly set up difference of electric potentials, or generate "electricity," it is yet the origin of the greater part of the phenomena of atmospheric electricity. It is the great agency for storing up the *potential energy derived from the sun*, and distributing it over the earth, and the phenomena of electricity, whether in the thunderstorm or the incessant quiet changes going on, are part of the process by which the potential energy stored in the vapour is transformed into the various forms of force employed by nature.

When we consider that 1 pound of water stores (speaking only in round numbers) over 700,000 foot-lbs. of energy, and that, as explained § 642, potential energy develops "electric potential" under proper conditions, we can have no difficulty in understanding where atmospheric electricity comes from.

So also the sudden changes of electric potential are intelligible if we imagine a mass of vapour as having undergone such changes as partly condense it into a cloud, a collection of minute electrified vesicles, which gradually coalesce into rain-drops; here we have conditions in which the charge is gradually accumulated upon surfaces growing smaller, therefore the potential rises until, as in the case of ordinary discharge—§§ 98, 104 (*d*)—the dielectric resistance of the air is overcome and discharge occurs as a flash of lightning, between the cloud and either another cloud or the surface of the earth, forming the other charged part of the electrified system.

897. When a flash of lightning occurs we can conceive it as due to the transformation of the potential energy of the vapour in the air, all along the track of the flash, which is the axis of

the field of force set up: this energy being thus transformed into dynamic electricity and its attendant work, the vapour condenses into water and we have the effect so commonly noticed in thunderstorms, of an instantaneous downpour of water accompanying the flash.

898. *Earthquakes and volcanic eruptions* are attended with powerful electric discharges, which are probably consequences of the mechanical energy expended, or of chemical action of water upon heated masses of earth. It is probable that further study will enable them to be foreseen by means of these actions, as the grinding of the rocks will furnish indications of the disturbance going on long before it culminates in the full action. Buried microphones transmit sound as a consequence. During the tremendous eruption of Mount Krakatoa in Java, August 1883, the telephones in Singapore, 500 miles distant, were so affected that conversation was impossible and a perfect roar as of a waterfall was heard, with occasional reports as of a pistol. This effect was due to action upon a short length of submerged cable by the tremors in the earth.

In like manner telephones are affected by lightning even at a considerable distance, partly by induction on the wires, partly by variation in the magnetic intensity, as described § 146.

899. *Waterspouts and cyclones* also are electrical in character, and it is stated that Professor Douglas of Michigan has produced artificial (or imitations of) cyclones by suspending a large plate of copper by silk threads and strongly charging it with electricity. The result is a miniature cyclone, funnel-shaped and whirling around, which, as the plate is moved over a table, picks up loose objects.

900. THUNDERSTORMS.—The common conception of lightning may almost be described as a belief that there is something packed away in the clouds, which at some uncertain moment falls from them as a "thunder-bolt," or rushes out upon the earth as a discharge of "electric fluid," with destructive effects, resembling in some degree those of the bursting of a reservoir of water. The conductor is regarded as having some *attraction* for the "bolt," and also as a pipe to receive and carry off the fluid. These ideas are not only erroneous scientifically, but they are the source of many practical mistakes in the setting up of conductors, which sometimes lead to fatal results.

Those who have comprehended the principles of static electricity explained in Chapter II. will see that they are applicable to the present subject, as lightning is strictly analogous to the *artificial electric* discharge. They will at once understand that the discharge does not merely issue from the clouds and rush to the earth, but that the latter fulfils a function just as important as that of the clouds; the latter are indeed the "prime conductors" of nature's great electrical machine, but the force is distributed over a vast "inductive circuit," of which the air and the earth form as much a part as the clouds themselves, and the discharge is a redistribution of force all over this inductive circuit, not across the air simply.

901. The thunder-cloud is to all intents a condenser plate upon which terminates a circuit, and there are two varieties of thunderstorm, which depend upon the nature of the opposite condensing plate. This may be another cloud above, or at a distance from the first; then the discharges occur between the clouds themselves, and the only effect on the earth is inductive, and usually slight; this is the case with what is called *sheet* lightning, in which the clouds are vividly illuminated, but there is no line of light visible. In the other class the surface of the earth forms the second condenser plate, the air and all bodies between the clouds and the earth are "polarized," and assume a condition analogous to that produced in the neighbourhood of an electric machine at work. Discharge at last occurs in one or more lines in which the resistance happens to be least, when the tension is greater than the resistance of the circuit can sustain. Very slight circumstances determine the direction of this discharge: an animal standing on the ground, a tree, the presence of extra moisture, or a metallic vein, or a range of piping in the ground may suffice.

902. This is very evident in the case of ships at sea: they will not only draw a flash of lightning, but there is good reason to believe that they frequently cause a change in the direction of the wind itself by the electrical conditions they set up. It is a common circumstance for a squall-cloud to arise and work half round a vessel, and at last come towards it and take it aback more or less suddenly. If the path of the cloud be traced out it will be found to be a parabola; the original motion being gradually diminished, and its direction diverted to the vessel. I have frequently seen this occur; on one occasion a heavy squall-cloud rose on the weather bow of a ship I was in; it crossed our course and went away to leeward, we running up nearer and nearer to its path: the cloud then stopped, rapidly returned towards us, against the wind we had, and as it reached above us, a violent change of wind occurred, the cloud threw out its charge, struck the fore and main top-gallant masts, and killed two men.

It will be easily conceived that a large vessel, with its three masts the only salient points arising from the earth's surface in the neighbourhood, must affect the electrical conditions around it, and that this may be the cause of sudden changes of wind. To this same order belong a variety of natural phenomena, such as what sailors call St. Elmo's Fire, when the points of masts and yards are tipped with lambent flames, resembling the brush discharge of our machines.

903. *Ball Lightning* is of so rare occurrence, and so dangerous and terrifying, that trustworthy accounts are not readily obtained. It appears to consist of a fiery globe of a reddish tint rotating on its axis, which slowly traverses the ground, sometimes at a few feet elevation, which in some cases explodes with a loud noise and emits vivid flashes of lightning in all directions. Its truly electric nature was long doubted because nothing resembling it was seen in electric experiments. But among the many curious effects obtained by M. Planté, with his enormous secondary battery and condenser arrangement, he has met with and described something strongly resembling ball lightning. The experiment consists of two conductors, one dipping into dilute acid, while the other is held a little above, after first dipping in: this produces a kind of brush discharge through films of moisture or vapour, which form an apparent globe of fire rotating on its axis.

Ball lightning appears to be a glow or brush discharge formed upon a mass of dust or vapour, and possibly connected with a small whirlwind; this serves as a focus upon which are concentrated the lines of force from a moving cloud, which carries this opposite pole along the ground, and ultimately either the excitement is quietly exhausted when the ball disappears, or it rises to the point of violent discharge. Many of the accounts of ball lightning indicate that the balls form in low and moist spots, and often in connection with fogs.

904. In the true thunderstorm the cloud consists of a series of layers or zones oppositely electrified, with a similarly arranged but opposite series on the earth beneath, the air between completing an electric circuit. Such a circuit is often extended over many miles, so that when a discharge occurs at one extremity a corresponding one in the reverse direction (sometimes called the back stroke) occurs at the other extremity, perhaps twenty miles away. The clouds themselves may be only 100 feet away, or two or three miles. Flashes of such length have indeed been measured by the angle occupied by the line of light and the period between the flash and the sound of the thunder. Several attempts have also been made to measure the time occupied by a discharge. Moving objects

when photographed by its light, appear as distinct as if stationary, but by means of revolving mirrors it has been ascertained that the actual duration of a flash is something less than 1-24,000th of a second, and it may be even less than a millionth; its apparent duration is an effect of our own eyes, due to what is called persistence of vision, owing to which we cannot lose an impression once produced in much less than a sixth of a second, on which principle are based so many optical toys. Some photographs are said to show much longer periods, but they cannot outweigh so many observations, § 910.

905. Perhaps the most complete and instructive account we have of the phenomena of a thunderstorm is that of Mr. Cross, who set up a collecting system of wires and experimental apparatus for the purpose of investigating the facts. He says:—

> When the cloud draws near, the pith balls suspended from the conductor open wide with either + or — electricity; and when the edge of the cloud is perpendicular to the exploring wire, a slow succession of discharges takes place between the brass ball of the conductor and one of equal size carefully connected with the nearest spot of moist ground. After a number of explosions of, say — electricity, which at first may be nine or ten a minute, a cessation occurs of some seconds or minutes, as the case may be, when about an equal number of explosions of + electricity follows, of similar force to the former, *indicating the passage of two oppositely and equally electrified zones of cloud.* Then follows a second zone of — electricity, occasioning several more discharges a minute than the first pair of zones, which rate of increase appears to vary according to the size and power of the cloud. . . . When the centre of the cloud is vertical to the wire the greatest effect takes place. . . . As the cloud passes onwards the opposite portions of the zones, which first affected the wire, come into play; and the effect is weakened with each successive pair till all dies away.

This description does not accord with the "fluid" theories, even in their modern form of ether, or with the idea of charges of free electricity: but it does agree with the conception of electricity as a polar force setting up stresses in matter, storing up energy in those stresses until the capacity is exceeded and the energy breaks forth as heat and mechanical work.

906. *The distance of a thunderstorm* may be reckoned by the interval between the flash and the first sound of the thunder, as sound travels about 1100 feet per second, which is nearly 4½ seconds per mile, while light travels practically in no time. The *duration of a peal* of thunder also gives an approximate measure of the space over which the storm extends.

907. The *real brightness* or illuminating power of lightning is vastly greater than it appears to be, because the eye takes time to receive the impression, and spreads over the period of one-sixth of a second the effect of energy actually expended in so much shorter an interval, § 904. A more just idea of the real

light-giving power is obtained when we reflect that this line of light (resembling the carbon thread of the incandescent lamps) is capable of illuminating a wide landscape.

908. Lightning is not a mere line, such as it appears to the sight—indeed, that line is possibly enough only a visual impression of a spark rapidly passing along the line; but this line is only the axis, the most intense part of a large area taking part in the act of discharge. There have been frequent cases of the same flash doing injury at several points, distant 30 or 40 yards from each other: also it is observed that a number of vines (which are specially sensitive to lightning) may be injured by the same stroke to as many as several hundred.

909. It is frequently stated that the bodies of those killed by lightning are marked by impressions of neighbouring objects, and even that these are, as it were, photographed upon the skins of people who have received little injury. How far this is true is uncertain, but there are many apparently authentic accounts of such effects: it seems probable enough that any object, such as a metallic surface, which modifies the path of the current, and to some extent condenses a charge upon it and serves as a fresh centre of action, may form the outlines of its shape. But what is most commonly observed are straggling lines, which look like branches of trees, and are frequently said to be pictures of neighbouring trees. Some have thought that these marks are due to congestion of the small superficial veins; but a comparison of many drawings and photographs of such markings with similar drawings or smoke pictures of the electric discharge will leave little doubt as to the identity of the two, and convince the mind that these markings are simply the spreading outwards of the lines of force where they entered the skin.

It is of more moment to those who are alarmed at lightning to understand that when a flash is seen all danger from it is passed; a person struck never sees the flash, and it would appear that this death is instantaneous and painless. But there are some constitutions to whom this can give little power to resist the unnerving influence of lightning, because this is not due to mere fear, but to a direct nervous influence, such as is experienced by many animals, and which many people experience in a minor degree in consequence of the electric conditions existing before a storm begins.

910. *Photographs of lightning* are often taken now that rapid acting lenses and plates are common: their similarity to the flashes given by the machines is very instructive. A wavy ribbon-like structure is often observed, § 912. In some cases, by using a moving plate, the apparent one flash has been resolved

into several rapidly following each other along the same path: these have of course been claimed as demonstrating the fashionable "oscillations" of electricity, but are quite as probably successive discharges of energy coming from a large area of badly conducting cloud.

911. *Dark flashes* or markings are found in many photographs, and have led to much imaginative discussion. They are probably mere optical effects, of which two explanations are given with experimental proofs: one cause is the presence of white clouds in the background cheating the camera; the other is very strikingly shown in a photograph by Mr. Adams, *Electrician*, xxi. p. 774, where the sun itself appears as a black ball. This is a photographic result of over exposure and indicates that the "dark" flash is really an extra bright one.

912 *Spiral path of lightning.*—It is often observed that spars and trees are marked with a deep spiral groove cut out of them; I observed it in the case mentioned, § 902. It might be considered that this results from the structure of timber, but I have seen an iron gas pipe similarly marked, with a line running along and round it as if cut with a graver. These facts may throw light upon the nature of conduction, and I would suggest that the ribbon markings in photographs, § 910' may be due to the path of the lightning taking a spiral form, more evident under some conditions of the atmosphere.

913. *Vagaries of lightning.*—In cases of damage the force appears to be distributed unreasonably, wandering about in various directions, and often missing seemingly tempting paths. This is often explained by the instantaneous nature of the action. This is a great mistake; lightning, instead of being hasty, is very deliberate, and feels its way most carefully. The actual discharge is a matter of the fraction of a second, but the growth of "stress" has been going on for several minutes, and during all this period "lines of force" have been building up through all the space influenced, and when the discharge occurs it merely follows these lines of stress already traced out, and the weak points give way under the growing stress.

914. According to experiments of Mr. De la Rue, § 116, a flash of lightning 1 mile long involves an E M F of some 3 or 4 million volts, which is about 633 volts per foot, or 16 times as great as the ordinary potentials observed by Sir W. Thomson, § 891. Lightning, though it be a current of electricity, does not obey the laws of Ohm; it does not distribute itself in the inverse ratio of the conductive resistances offering it a path; it will leave a conducting wire to leap across an air space offering many thousand times the resistance. There are various ways

of looking at this fact, which, though long known, has of late been specially studied by Dr. O. Lodge.

915. He has shown more clearly than had been perceived before the part played by "inductance" and the actions examined § 498, and especially that we have to consider not only the resistance of a conductor but its impedance, § 523. It is, however, doubtful whether any experiments with Leyden jars can be identical with the operations of nature's electric discharge, and the vast inductive circuits she puts in operation.

916. *Oscillation* is also a conception which he has rendered fashionable, but the theoretical use of which has great dangers. The idea is that when a sudden stress is put upon a circuit the first effect is to produce a succession of alternating, to and fro currents, gradually giving way to the continuous flux due to the stress. The analogy is to the case of a pendulum struck sharply, or practically to that of a spring which vibrates before yielding to a blow. Such currents are experimentally proved to be produced in many cases: but it should be remembered that they are purely *phenomena of the conductor*, not of electricity itself; they are results of the inertia of matter, § 498 (*a*). Therefore it is wrong to apply them, as is now constantly done, to theories of the nature of electricity or electric transmission; the vibration of the molecules of a conductor under a suddenly applied stress cannot properly be mixed up with the impressed undulations, § 887, of the Hertz experiments to prove that electric oscillations exist. This is constantly done by eminent men, but it is very bad logic.

917. *The alternative path* is also a true fact, and Dr. Lodge's experimental illustrations are admirable; but this also has a simple aspect. It has been long known, § 914, that natural lightning or Leyden jar discharges will leave a thoroughly good conductor and break across the air space of a million-fold resistance, and the recognition of "impedance" clears away the difficulties of this fact, which has many mechanical analogues, as in the case of a candle fired at a board, which it penetrates under violent impact, while it would crush up under a steady pressure.

918. Whenever the impedance of any part of a circuit is very great, a momentary current may jump over that part of the circuit and take a path which, while of greater conductive resistance, gives way more quickly. This is of great importance in designing lightning conductors, but it in no way involves any reactive influence on the remaining part of the lightning path; it does not imply that the lightning on the whole is "oscillatory," even if oscillations could be proved to be set up

in the current which still traverses the good conductor and alternative path. Any impedance resulting in oscillation would act as a counter E M F when in opposition to the real stress, and a real reverse *current* might exist *in the conductor* at that instant, while the discharge as a whole would be continuous in direction, though possibly variable in degree; the result might therefore be the prolongation of the duration of a flash, and perhaps an apparent breaking of it up into several periods, or seemingly separate flashes following identically the same track —conditions which several photographs reveal.

919. The foregoing considerations as to the nature of the lightning discharge will enable us to see what are the true principles of conductors to avoid its effects. They are not intended to attract or convey a *discharge from* the clouds, although they must undoubtedly invite the discharge by setting up a line of low resistance; but their object is to lower the stress in the *space to be protected*, and therefore to diminish the likelihood and frequency of actual discharges. They do this in a twofold manner:—

(1) They practically raise the earth's surface to such a curved height as corresponds to the electric relations of the conductor and the air; not in an exact invariable form, as some suppose the protected area to assume; but still, roughly in a cone from the apex of the conductor, and of a radius perhaps equal to half the height of the point, but this applies only to the rod itself. When buildings are in the included cone no law can be given, as the conditions are affected by their form, materials, and contents. Whatever the space protected may be, within it the conductor lowers or nullifies the condition of tension, transferring it to the space outside the cone, &c. (2) They react also upon the exterior space in the direction of a reversed cone, by the discharging properties of points when forming part of a polarized area, as explained § 96. When a point connected to "earth," or the rubber of a machine, is approached towards the prime conductor, the latter cannot be charged, but a brush discharge occurs and a current is produced instead. The lightning conductor acts in the same manner: as soon as the charged cloud approaches, and would begin to set up an "inductive circuit" in the air to the earth beneath it, a current begins to flow quietly in the conductor, the potential above it is rapidly lowered, and may not be able to accumulate sufficiently for a violent discharge, i. e. a lightning flash, at all; but if it does, the discharge will occur through the space between the cloud and the outer area of the conductor's cone, and the conductor takes it up in the form of a momentary increase of current. But

it does not follow that the whole discharge traverses the conductor: surrounding space in all probability takes a part.

920. These principles settle conclusively all questions as to the construction of lightning conductors. Their object should be to connect to earth every portion of a building; and as this is actually possible only with metal buildings, they should connect every salient point and as much of the surface as possible, so as to extend around the building the area of low potential, or artificial " earth " surface opposed to the cloud. Chimneys require especial attention, because they are tubes lined with conducting material, containing warmer air, and if with fires, then extending a comparatively good conducting column of warm air towards the cloud, and so inviting a discharge; hence it is that lightning almost always enters a house by the chimneys. All doors and windows causing currents of air should be closed during a thunderstorm.

The ideal protection is that of an iron ship with iron wire rigging, where a copper strip is carried across the " dead eyes " so as to connect the rigging to the hull: it is scarcely possible for such a ship to be struck.

921. The prime essential is a *good earth connection*, which is best obtained in water in good electric connection to the mass of the surrounding earth. Water and gas mains provide the best if the conductor is well secured to them; next to them is the metal shaft of a good pump, in a well constantly supplied by springs; then ponds or ditches. What is required is a large metal surface terminating the conductor, and in contact with a stratum of moist earth, so that a hole sunk into wet gravel, into which the conductor is led, and surrounded with a quantity of coke to increase its surfaces of contact, will answer, but dry clay, or rock, is not safe, and a connection to water contained in a mere cistern, as is sometimes employed, is worse than useless. This connection should, if possible, surround the building by means of rods from its various corners, either led to different earth plates, or else continued by a rod round the house to one earth connection.

922. Every piece of metal-work about the building should be utilized, such as ridge-caps, guttering, and water pipes. These cannot be trusted as conductors because of the joints in them, unless these are soldered, but they will help to form a protecting network around the building. For the same reason a connection should be led from the bottom of the down pipes from the gutters to the nearest suitable earth, though a very good but variable earth connection is set up from these by the water itself during heavy rain. The lower parts of bell-wires

may also be advantageously connected to an earth, such as the nearest gas or water pipes, as several accidents have occurred from their having either received a direct charge through the walls, or having a violent current induced in them: composition gas pipes should not be made part of a circuit, as they melt easily and might cause a fire.

923. The terminals should be attached to all high or salient points, most particularly chimney-stacks: if these are wide and contain several chimneys, it is safer to have two points, though usually one is sufficient; but the kitchen chimney, or any one commonly used, and therefore lined with soot, and containing warm air, should be specially attended to. The points may be made of rods of 1-inch iron drawn out to a point, rising 2 or 3 feet above the building; they are better also for galvanizing. There is no advantage in any of the fancy points, patented or otherwise. The thickness of the conductor depends upon the size and height of the building. A factory chimney or church steeple should have a copper conductor of at least ½-inch section, well protected against injury; for smaller buildings, iron may be used instead of copper. In ordinary cases galvanized iron wire of about a ¼-inch diameter (such as is used for telegraphic purposes) will answer, if led separately from various salient points, and carried down the different sides of the house and connected, as above described, to the guttering, &c., but for a single conductor at least ½-inch rod should be used. It appears from the experiments of Prof. Hughes and Dr. Lodge that flat sheet is to be preferred to thick rods, as having less "impedance," and that galvanized sheet iron may be used in place of copper. But all joints should be well soldered in any case.

924. Conductors should *never be insulated* from the building, but, on the contrary, as much of the surface as possible should be connected to the conductor. Electrometers, &c., are often surrounded with a cage of wire connected to earth or the negative pole of the source, in order to prevent them from being affected by external electric disturbances. That is exactly what we require to do with our buildings: an iron house well connected to earth would not only be perfectly safe, but its inmates would scarcely feel any of the effects usually produced on the nervous system by "thundery" weather, except so far as these are due to heat. The object aimed at in a lightning conductor should be to approach that condition as nearly as possible; to obtain an inclosed area within a conducting envelope provided with points and connected to earth.

925. It has often been asserted on theoretical principles that

a large expanse of iron roofing is a perfect protection. The gas pipe mentioned § 912 supported a windsail passed through an iron roof covering nearly half an acre, carried on iron pillars, and provided with a good lightning conductor terminating in a canal. Yet it was struck, and the cords which fixed the windsail to it were burnt: but a most excellent earth was near the foot of the pipe and no further damage was done.

926. Examination of conductors shows that many do not give trustworthy protection; they fail by imperfect junctions at some part, or by imperfect earth connection. Some people say that even a bad conductor is better than none, as at all events it will protect the principal structure, even though explosive discharge occurs near its bottom. But this is very doubtful: § 919 will indicate that they may draw a discharge which might not otherwise occur; § 914 will show also that there is no telling where the lateral discharge might occur; machinery or engine shafting might draw it in any direction into the building.

927. Conductors should undergo periodical tests, and it would be wise to provide the means of making such tests perfect. This could be done by attaching a well-insulated copper wire to the upper extremity, connecting its lower end also to the conductor by a screw, so that ordinarily it should form part of the conductor: this would enable the perfect continuity of the conductor to be tested at any time, by measuring the resistance of the conductor from the screws to its upper end, returning through the test wire.

An independent "earth" is also requisite to test the earth connection: but as the resistance would be that of these two earths, a third is requisite, to make sure that the second is perfect, and also that it really is independent, as temporary connections made to gas or water mains might really be a complete metallic circuit to the lightning conductor itself.

Such temporary earths can be made by soaking the soil well with water and driving in an iron crowbar: the soil of a stable is well suited for obtaining good earth, or the stem of a metal pump may be used. Two such earths being provided, the resistance between them can be measured, and then that between each of them and the conductor: the resistance should be measured twice with the battery current reversed, to compensate for any polarization current set up by any difference at the earth plates. The actual resistance of each earth may thus be arrived at. The resistance of a good "earth" may be as low as a quarter ohm, and ought not to exceed half an ohm. The *total* resistance of a lightning conductor from point to earth ought to be brought to at most 1 ohm, and certainly should not exceed 2 ohms: it is, however, common to find a resistance of several hundred ohms in conductors attached to important public buildings.

928. It may be well to explain here a subject which is a difficulty to many minds. Faraday stated that the electricity contained in a grain of water is equal to that in a powerful flash of lightning; some quote him as saying it is equal to that of a severe thunderstorm. Now it is evident that the energy of a grain of water is foot-lbs. $6841 \div 9 = 760$, and it is obviously absurd to compare this with the power exerted by a flash of lightning: it is only equal to warming 1 pound of water 1° Fahr., or the work of a man for five minutes.

When Faraday made this statement he was beginning the study of electric quantities. Volts, amperes, and ohms were then undreamed of; nothing but vague generalities had been attained to. It is therefore not to be wondered at that while he displayed his wonderful experimental powers in making comparative measurements, he compared together things having no relation. It is rather strange that while his statements are frequently requoted, their true interpretation should not be given. Before doing so it may be well to bring together the statements of Faraday and other workers in the same direction.

929. Faraday found that to decompose a grain of water required a current for $3\frac{3}{4}$ minutes capable of keeping red hot a platinum wire 1-104th of an inch in diameter. We can express that as a current of 3·13 amperes, or a quantity of 704·37 coulombs. He found that to effect the same decomposition by the machine required 800,000 charges of 15 Leyden jars, each having 184 square inches of coated glass. Each of those charges, produced by 30 turns of a 50-inch plate machine, was capable of killing a rat, and was equivalent, chemically, to the action of a platinum and zinc wire each one-eighteenth of an inch in diameter, immersed five-eighths of an inch in weak acidulated water for about three seconds.

930. Weber has calculated that the charge due to 1 grain of water, if placed on a cloud 1000 metres (3281 feet) above the earth, would exert an attractive force equal to 1497 tons, and Becquerel arrived at somewhat similar figures. Weber compared the charge of a Leyden jar, of which the static value was measured by the torsion electrometer, with the battery current producing equal effect upon a galvanometer. He found that $16{,}573 \times 10^9$ units of electricity decomposed 1 milligramme of water, and reckoned that on a cloud 1000 metres high an attractive force of 226,800 kilogrammes, or 208 tons, would be

exerted. He also reckoned that, assuming the oxygen and hydrogen atoms of this water were separately ranged upon threads 1 millimetre long, then to effect the decomposition the threads would require to be drawn apart with a force of 147,380 kilogrammes or 145 tons.

931. Now let us translate these results into modern expressions. The current value of 1 grain of water, § 929, is 704·37 coulombs. What is the condenser which will replace Faraday's 800,000 charges, which represents 1 charge of 15,333,335 square feet, or 1 Leyden jar with a coated surface of 352 acres, which would be a moderate sized thunder-cloud, being more than half a square mile? The actual size of the condenser would depend on the potential, and starting with the unit 1 volt, we require a capacity of 704·37 farads, or 704,370,000 micro-farads, § 425. Taking 3·5 miles of cable as the physical micro-farad, we find that 1 volt, or say 1 Daniell cell, would require 2465 million miles to receive the charge, or enough to wind 1200 times round the earth and moon, or twice round the earth's orbit. Or if we take the earth's (imaginary) capacity, § 424, as 700 micro-farads, it would charge to 1 volt a million such worlds as ours.

932. Leaving all these fantastic unrealities, what is the common sense of the matter? It is simply a question of the relation of the two quantities Q and Q of § 642, of Q and Q^2 of § 15, or of Q and E of the ordinary formulæ; that is to say, of the two functions which *together* constitute what we mean by electricity, while the word is frequently applied (as in this case) to either one of them: these two are Q, *quantity*, or the molecular action of matter, and E, *energy*, the potential under which the molecular action occurs, the stress put on the circuit. All the ideas we have been considering depend on the imaginary, but impossible, isolation of Q; the real phenomena depend on $Q \times E$, the matter and energy which together constitute electricity.

933. Now in the case of water, E is a potential of less than 1·5 volt, and what we have to take into account in the case of the grain of water is therefore $Q \times E \times k$, or $704 \times 1{\cdot}5 \times {\cdot}7373$, this being the constant expressing the energy in foot-lbs., which gives us just the 760 foot-lbs. which we know is the mechanical equivalent, § 927, of the grain of water. In the case of the lightning flash, the Q of which we assume to be this same grain of water, we have a potential unknown, but which we may take to be that arrived at in § 506. Thus we have

$$704 \times 3{,}604{,}000 \times {\cdot}7373 = 1{,}872{,}000{,}000 \text{ foot-lbs.}$$

This figure enables us to understand why this "grain of water" can produce such tremendous mechanical effects when concentrating this energy upon some point of high resistance in an infinitesimal fraction of a second.

934. But the *current* of such a flash is not a small one, as is often stated; if we take the time of the discharge as 1-20,000th of a second, 704 ÷ 20,000 = 14 million amperes. From this it is pretty clear that no lightning conductor is ever called upon to carry such a current; either it lowers the potential, producing a steady current and reducing the actual flash, when it occurs, to a very small one, momentarily raising the current, or it only carries a small part of the discharge which is largely distributed over surrounding space.

935. It may be of interest to show that Dr. Lodge has arrived by a different process at much the same results as those I have given. He says that the total energy of an area of cloud may be estimated from the fact that the electric tension of air, § 96, is limited to a half gramme weight per square centimetre when disruption occurs, so that its energy as a dielectric is $98\frac{1}{2}$ ergs per cubic centimetre and per cubic mile is

$$\frac{4110 \times 10^{2}}{2 \times 3\cdot \times 10^{7}} \text{ foot tons} = 70,000,000.$$

An electric quantity of 2176×10^{8} elec. stat. units per square mile would give a bursting tension for a mile length, and this is just about 70 coulombs, or not enough to decompose $\frac{1}{7}$th of a grain of water. Of course the whole stored energy of a cubic mile is not discharged in one flash, though the whole electric quantity would operate.

CHAPTER XII.

ELECTRO-MAGNETISM.

936. Throughout these pages electric transmission has been regarded mainly as a breaking up and reformation of the molecules which form the polarized chain or circuit, this being the action which undoubtedly does occur in electrolysis. But no single conception will convey the whole of any scientific truth, and it has been indicated, especially in §§ 609–11 and 667, that transmission may be effected by other means (such as *rotation* of the molecules) dependent upon the same causes, viz., polar attractions of matter, which in electrolysis produce actual disruption.

937. ROTATION OF MOLECULES.—A rotation of molecules involving a reversal of their polar arrangement will fulfil all the conditions required, and the relations between magnets and electric currents indicate that such a rotation does occur in solid conductors, and that the direction of what we call the current depends upon whether this rotation takes place on an axis inclined to the right hand or to the left of the polarized chain itself. This idea seems to be confirmed by the researches of Prof. Hughes, who finds a + or − current produced in a wire around a magnetized bar according as torsion is applied to the bar in one or other direction.

938. Whenever a magnetic body and an electric conductor are brought near to each other, or moved in each other's neighbourhood, they react upon each other if either is under the influence of either force, magnetism or electricity. A magnet will produce a current in the conductor if either is moved under certain conditions; electricity in motion as current confers magnetism on a magnetic substance. The reason is that the two are really different manifestations of the same force, and due to different actions of molecules in a state of polarization; the electric action is that exerted in the line of polarization; magnetism is the action at right angles to the line of polarization; it is exerted in every direction at right angles, and, as a consequence, magnetism has in itself no directive power; the *directive* power of magnets is not the property of any single *magnetic* substance, but is the consequence of the mutual

reaction of two or more such objects. It is the possession of magnetism by the earth, which therefore acts as one such body, that confers upon magnets their apparent directive power.

939. The source of all the mutual actions of magnets and currents is to be found in that property of the molecules of matter which we call *induction*, a power of acting externally upon other molecules. Within the electric circuit itself this power sets up the condition of "polarization," or arrangement of molecules in regular sequence (+ −) (+ −) (+ −); but besides this action *in the circuit*, a similar action is exerted *around the circuit*, which tends to place surrounding molecules in a parallel polar order. But while the first action is consistent with a transmission of energy along the circuit, and is thus of a dynamic character, involving a constant rotation of the molecules on their axes, the second is static, and changes only when there is a change of conditions.

940. *Magnetism is a function of energy:* it is, as in many other cases, a force manifested by the particles of matter, when charged with energy. It is a question whether magnetism is a force actually possessed by matter itself, or whether matter possesses only the faculty of exerting it. The present tendency is to believe that magnetism is self-existent; that it is not manifested ordinarily by matter because its ultimate magnetic elements are closed in pairs as shown, Fig. 65, p. 319, and that the energy of magnetizing is employed in opening these pairs out into the order shown, § 610. This is the theory adopted by Prof. Hughes, and more fully worked out of late by Prof. Ewing.

941. But magnetism may be, like di-electric capacity, not an actually existing force, but something in the structure of some forms of matter which enables them to assume a temporary state, in which they manifest exceptional force, just as a charged di-electric does: this conception appears to me to best explain the facts, but either will serve the purpose, if we consider that the actual effects are those of energy applied from without.

942. It is usual to speak of the *molecular* structure of magnets, and as though the ultimate magnets of Ewing's theory were really the molecules as defined in chemistry: of this there is no evidence whatever. These *magnetic molecules*, which it might be less confusing to call "particles," or some other name without so special a meaning as molecule, may be *aggregates of real molecules*, and magnetism a force due to such aggregation: the phenomena of the "critical point," the temperature associated with evident change of structure and energy, with loss of magnetic power, and with "recalescence" evidencing a release

of internal energy, may well indicate a breaking up of molecular aggregations, such as occurs with atoms in cases of allotropy, § 672.

943. *Magnetism is of the same order as charge;* it is a static condition of the molecules, set up by energy absorbed from an electric current (or other source); while this condition is being assumed the process acts as a resistance; but once set up, it is static, requires no more energy, and the energy will be retained, or given up as a current, according to the conditions.

944. To apprehend the consequences we should regard the electric circuit as a simple chain of polar molecules, which I shall do by drawing them as ellipses, of which the dark part will represent the + end, or the direction in which we may conceive the supposed electric current to be travelling; the white, or – end, being that connected to the positive pole of the battery. Fig. 71 is a section of such a chain, looked at from the positive pole, that is to say, the – end facing the observer, with the line of electric polarization passing through the centre. Fig. 71 is, it will be seen, a transverse section of the molecule, Fig. 27, p. 84. But it must be understood that these show only the static stresses of magnetism, and that while current may be usefully typified by such diagrams, they cannot show the motions which constitute real current; they are only aids to the imagination, not real pictures. In this way Fig. 72 may typify a current in a conductor with its external static actions: my molecular ellipses will be seen to correspond in magnets to the opened-out magnetic elements of Prof. Ewing's theory.

Fig. 71.

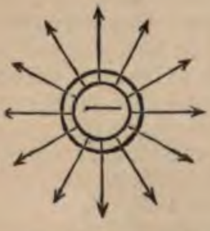
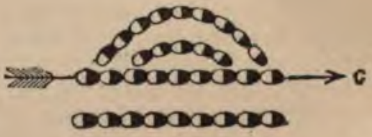


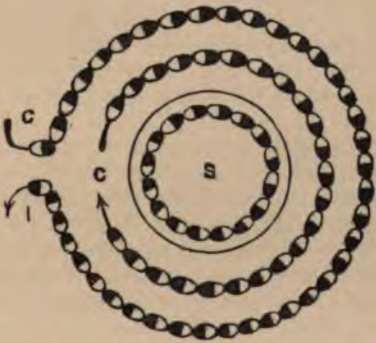
Fig. 72.



945. If we conceive the polarized chain C, of Fig. 72, to be formed into a circle, as in Fig. 73, we have the general relations of currents and magnets. Let S be a section of a bar of steel; its molecules arrange themselves in closed chains, § 133, Fig. 30; *and as* steel possesses the power of retaining this condition, it *becomes a* magnet; the forces exerted at right angles to the

direction of polarization, all combining and acting in the line of the bar, as shown in the upper bar S N, Fig. 76, and also in Figs. 74 and 75. The difference between the two extreme faces of this bar is that, looked at from the exterior, the lines of polarization turn to the right in S and to the left in N, as seen in the two polar faces shown in Fig. 76. There is no difference of property, no inherent directive tendency in these ends; but in England we call the face S the south pole of the magnet because it ranges itself in the earth's magnetic field, facing to the south pole of the earth. In France they call it the N., or Boreal pole, because the north pole of the earth has, in fact, the characters of what we call the S pole of a bar magnet, § 869.

FIG. 73.



946. But action takes place externally, as well as within the ring. If I C, Fig. 73, is regarded as a ring of wire, its molecules, of necessity, swing into the polar order, and in doing so a momentary current is generated in this "secondary" wire; but only one wave of action is produced, no current continues to flow in I C. As soon as the primary current ceases, all the molecules resume their normal position, and in the act of doing so a current is again set up in I C, but in the opposite direction to the first.

947. If S is iron, instead of steel, it loses its magnetism, and the energy it has stored up is employed in increasing the [illegible] he surthe current in I C, and also in producing an *extra* cu [illegible] netic itself, continued after the battery is cut off. A pa [illegible] *field*, energy also sets up circular currents within the m [illegible] rmed these, which are called Foucault currents from their [illegible] conare wasted in heating the iron, and are partly the cau [illegible] raws

is now called "hysteresis," § 972. It is to avoid this that cores are made of bundles of wires or sheets.

948. If S, instead of being a bar of iron or a bundle of iron wires, is made of an insulated iron wire wound up in a helix similar to the other wires, it will still act as a magnet, though less forcibly, owing to the breaks in the longitudinal or magnetic lines, but the *extra* current will then be formed within itself and the wire will give off sparks. This fact, which I discovered many years ago and included long after in a patent, has uses as yet not developed.

949. The current in the secondary wire is in the reverse direction to that of C itself when contact is made: at breaking circuit the induced current is in the same direction as that of C. As these currents are each the result of single and equal swings of the molecules, their "quantity" is the same, for quantity is simply a function of the molecular actions. But the E M F of the breaking current is much the greatest. The reason is obvious: in the first, energy is being taken up rather in the core S than in the wire I C: in the last, that energy is given up to I C and added to its own charge.

950. The *direction* of these and all actions among currents and magnets, *induced* by motion (which includes the setting up or cessation of a current, these being equivalent to a motion of approach or withdrawal), is governed by a law formulated by Lenz. *The direction of the current set up by any motion will be such as will resist that motion, and vice versâ.* Now currents having the *same* direction *attract* each other: therefore a current in the *opposite* direction, which *repels*, is set up. The order of the polarization in magnets (Fig. 73) acts as would the corresponding current, represented by C. We may see in this some analogy to the action of two wheels in contact; when one is rotated in one direction, it sets up, in the other, a motion in the opposite direction. Thus the current at "break" is in the same direction as the primary current, as this resists the demagnetization or withdrawal of the magnetic energy, or magnet.

951. In consequence of these relations, a wire wound round a bar of iron magnetizes it in a direction determined by the direction in which the wire is wound. On the other hand, if
magnetized by any external means, as by bringing
gnet in contact or neighbourhood, a current will be
the wire, and the direction will depend upon that of
ism set up, and also upon the direction in which the
und. Helices are called *dextrorsal* or *right-handed*
ing at them from the end at which the current enters
the coiling of the wire commences, the wire turn

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945. If we
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becomes a m

from left to right over the core as the hands of a watch. Fig. 74 is a right-handed helix, and, as it shows, such helices give South polarity to the end at which the current enters. In *sinistrorsal* or *left-handed* helices the wire, under like conditions, turns from right to left over the core, as in Fig. 75, and gives North polarity to the end at which the current enters. A right-handed helix becomes left-handed if looked at from the other end; therefore when the wire of a right-handed helix returns over itself, by continuing to wind in the same direction, the upper layer becomes a left-handed helix; but as the direction of the current reverses as regards the core, the mutual reaction of wire and core is the same in all parts.

FIG. 74.

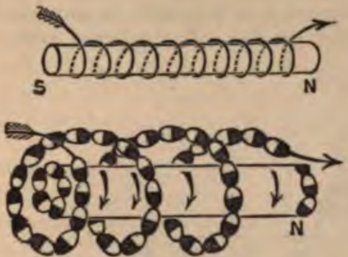
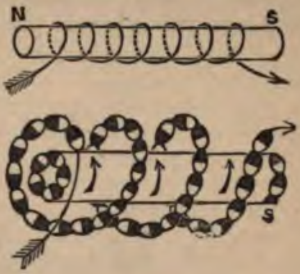


FIG. 75.



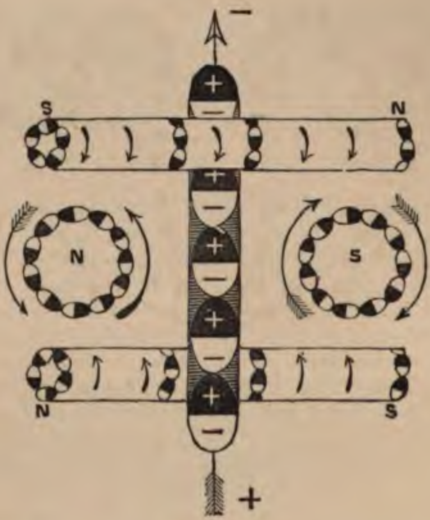
952. Fig. 76 carries these relations a stage farther. The conductor is shown as a line of molecules upon the arrow which marks the direction of the current; four magnetic bars surround it, and the molecular arrangement of these shows why they place themselves as they do (assuming the earth's influence to be neutralized): the ends of the two side magnets correspond with those in Figs. 74 and 75 as the other two magnets do with the bars in those figures. The magnets arrange themselves as though the lines of polarization were currents parallel with the current itself, and as the corresponding helices would if currents were traversing them.

953. We have now to consider how the magnets react. A magnet is not merely a bar of metal; it is linked to the surrounding matter in which are completed the lines of magnetic force, and which constitutes what is called a *magnetic field*, which field is an integral part of the magnet, whether formed in surrounding matter, or concentrated in a mass of iron connecting its poles. When a magnetic substance is near, it draws

these lines towards itself, and by entering them becomes magnetized, but in ordinary conditions we may regard the lines of force as enclosing an elliptic space round the magnet, as shown Fig. 31, p. 89, and explained §§ 137–8.

Fig. 77 gives the idea more completely. It shows that the lines of force of the field, enclosing the ellipse, may be looked at from a twofold aspect. They are commonly treated as set up by the *poles* of the magnet, and as completing the circuits of *magnetic* polarity; for many purposes it is desirable to so regard them, and this view is presented by the elliptic lines, which

FIG. 76.

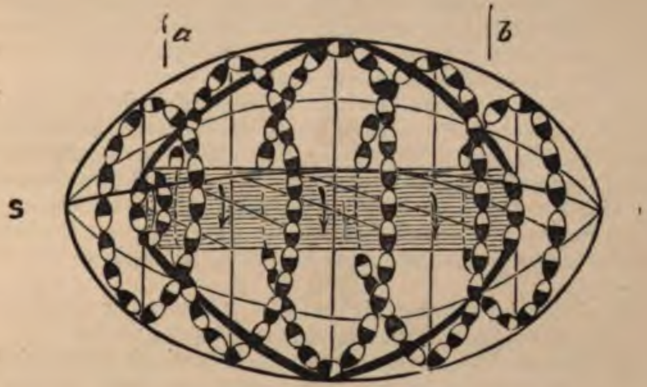


correspond to the arrows of Fig. 31. But we may with equal truth consider the polarized condition as set up by the circular polarization of the magnet forming the *vertical* circles, and so regard the elliptic or magnetic lines as set up indirectly by the action at right angles of these circles; both actions no doubt unite as real causes of the magnetic field.

954. We shall thus understand why the *inductive* power of a magnet is so much greater at its middle, while its *attractive* power is so much greater at its ends. The attraction is a function of the general law that parallel currents attract each other; there is, *in fact, in* all spiral conductors a tendency to close up, because

of this attraction between all the partial currents. Now if we conceive another figure like Fig. 77 brought near it endwise, it is evident that to make the lines of polarization alike, the north end of one must be presented to the south end of the other, and that then not only do the circles of the bars agree, while all the circles of each magnet, internal and external, attract each other, but the projecting lines of force of each magnet become incorporated with those of the other, and the result is a new elliptic field, as shown Fig. 32, p. 90. Hence, naturally, long magnets have the greatest attractive power, for they may be regarded as many small ones, combining their magnetic force, just as the union of batteries in series combines their E M F's. But as to induction, the external circles are affected by those of the bar more powerfully at the middle than those at the ends can be by the whole length of the magnet, as this influence obeys the law of the squares of the distance; therefore, speaking roughly for illustration sake, if we consider the inductive action of each circle of the bar to be equal, and call it 10, a circle at the middle will have a force of 20 exerted upon it by the two end circles, but a circle at the one end will be acted upon by the middle, 10, and the other end, whose distance is doubled, will give only $10 \div 2^2$ or 2·5, a total of 12·5 upon an end circle against 20 on the middle circle.

FIG. 77.



955. All who wish to understand magnetic principles should experiment on the "field" for themselves and not rely upon

figures given in books. Mount a sheet of glass upon feet, so that magnets and apparatus can be placed below it while iron filings are sprinkled lightly from a pepper-caster upon the glass, which should be vibrated by tapping gently: it is best to make the filings from a soft iron bar with a rather coarse file, as they ought to be of good iron, not with cast iron or steel mixed. If the glass is coated with a film of paraffin wax, the lines can be fixed by warming the glass.

956. It should be remembered that the curves of filings do not represent the lines of force really existing in space, because the presence of iron concentrates the field; the filings becoming an armature to the magnet. The real lines in space may be traced out by a very short magnet needle freely suspended: this places itself on the lines existing at any spot, or more correctly, tangentially to them, as they are curves.

957. Besides the concrete conceptions which fix ideas it is necessary to use the abstractions which the mathematicians have defined, in order to understand what knowledge has been gained, and the accepted symbols connected with the C G S system, in order to apply that knowledge to practical purposes, and a concise description will be a useful introduction to the applications of electro-magnetism. The most important symbols to be used are:—

H	Intensity of magnetizing force. The number of "lines" per square centimetre in air.
B	Internal magnetism: magnetic induction: permeation; number of "lines" per square centimetre within a magnet.
μ	Permeability: magnetic capacity.
R	Reluctance, reciprocal of permeance.
N	Total number of lines, magnetic flux, analogue of current.
I	Intensity of magnetism: number of lines per square centimetre, moment per cubic centimetre.
C n	Ampere turns.
A	Area of section.
4π	ratio of surface of a sphere to the diameter.

958. There is a tendency to compare magnetism with electricity, and to set up ideas and formulæ in magnetism similar to those of Ohm. For some reasons this has a practical advantage united to a most serious disadvantage: that is, some use may be made of the idea in designing dynamos, &c., but the idea itsel is false and therefore sure to mislead. There is *nothing in magnetism analogous to the current in electricity.* People assert that there is, but ignore this fundamental distinction, *magnetism*

expends no energy and current does. Energy is expended in producing magnetism, and in doing work by it, but not in maintaining the magnetic state: the proof is that the resistance of an electro-magnet wire is the same (after the first production) whether the iron be in the core or not; the energy is wholly employed in maintaining *current*, none in sustaining the magnetism.

959. There is, however, a true electric analogue, in the charge of a condenser: di-electric capacity (permittance Mr. O. Heaviside calls it) and magnetic capacity or permeability are truly comparable, while conductivity is of an entirely different order. Magnetism, like charge, is a *stress* which stores energy, current is a *flux* which expends energy continuously. Still a true *magnetic circuit* exists, because magnetism consists in closed lines of stress, as does the inductive circuit.

960. *Magnetizing force* H is therefore frequently called *magneto-motive force* and in the C G S system it is $40\,\pi \times C\,n = 125{\cdot}66$ multiplied by current turns for one square centimetre. It is the power of producing n lines in air; in the ordinary units, area and length being in centimetres, it is for rings,

$$H = \frac{4\,\pi}{10} \times \frac{C\,n}{l} = 1{\cdot}2566 \times \frac{C\,n}{l}$$

961. *Internal magnetism* B, is the number of lines per square centimetre section of the magnets or $B = \mu \times H$: its maximum is at the middle section where all the lines may be considered to originate in each direction. (See leakage.) Mr. Kapp introduced a compound unit of number of C G S lines per square inch; some of the data may be given in this compound but it is not used in the formulæ to avoid confusion. $B = 4\,\pi\,I + H$ (or $-H$) and all its lines pass out of the magnet into the curves of the field.

962. *Permeability* μ is based on the magnetic capacity of air $= 1$: that of all ordinary para-magnetic substances except the magnetic metals is also closely 1, while that of dia-magnetic substances is -1, but only slightly so; $\mu = B \div H$ and is measured by the number of lines which unit H produces in a square centimetre section of the substance. (See saturation.)

963. *Permeance* should correspond to conductance and so represent the total lines of a system, as permeability does those of unit area: but the word is used somewhat indefinitely. The presence of iron near a magnet, or in its highest form, the placing the armature on a horseshoe electro-magnet increases the *permeance* of the circuit, the number of lines B in the iron, though

it does not affect the *permeability* of the iron; it is equivalent to reducing the resistance in electricity.

964. *Number of lines* N represents the total magnetism represented by the lines, as B represents the lines per unit area, and corresponds in the magnetic circuit to current in Ohm's formulæ.

$$\begin{array}{c}\text{Magnetic flux}\\ \text{or}\\ \text{Total lines}\end{array} = \frac{\text{Magneto motive force}}{\text{Reluctance}} = \mathsf{N} = \frac{\mathsf{H}}{\mathsf{R}}.$$

965. *Reluctance* is Mr. O. Heaviside's name, now pretty generally used for the analogue of electric resistance, and like that it is a mere invention, the reciprocal of *permeance*. It is even less a real thing than the artificial electric resistance, for that is really measured and counted (though only as conductors), and by it we recognize the reality, the conductance: but in magnetism it is the permeability alone that we measure, and then manufacture its reciprocal into a function which has no real existence, merely to get something like Ohm's formula in magnetic calculations. Many people even call it magnetic *resistance*. I have used R as its symbol.

966. The idea of resistance is useful, however, in considering the effect of distance, or air space: thus a mere cut across a bar of iron however truly faced, as in the junctions of the legs and yokes of electro-magnets, introduces a *resistance* equivalent to increased length of iron: but this is a true resistance, and unlike the artificial electric R, it varies with the intensity of magnetism, is important with low forces, and becomes insignificant in very strong magnets.

967. *Intensity of magnetism* I, is the number of lines per square centimetre at any section of the magnet or field. it corresponds to "density of current." Unit I is therefore related to the conventional "line" as if it occupied 1 square centimetre, and is also the unit "moment per cubic centimetre."

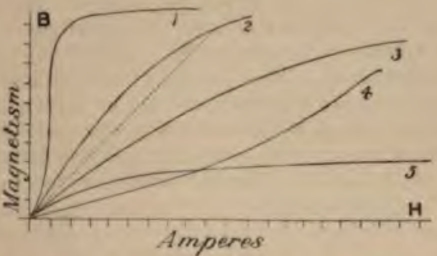
968. *A line of force* is a pure convention necessary to give definiteness in calculation to our conceptions. We see the lines or curves produced by iron filings, and they show us a condition which really exist in space, but these lines are not the lines o the formulæ, nor do the lines themselves exist in space: they are produced by the filings, and vary with their fineness. But in truth the whole space is filled with the power which the lines exhibit to us. Therefore some prefer to speak o "tubes of force" rather than lines. The action between two unit poles, § 150, 1 centimetre apart, represents the unit line.

969. *Saturation* is the complete satisfying of the magnetic

capacity: if we adopt Ewing's theory that magnetization is the ranging in polar order of already existing magnetic particles, saturation is the point at which all the particles are ranged in order and no added force can increase their number. If we conceive magnets as composed of molecules or groups, § 942, upon which a special condition is induced for the time by absorbed energy, then saturation is the point at which this process is completed.

970. Whichever may be the mode, the process is gradual and dependent upon the specific properties of the substance, and possibly is never fully completed; what we really deal with is the limit at which, for any substance, the increase of magnetism by added power is so small as not to be worth effecting: this is the practical limit of permeability. In good soft iron B may rise to 20,000 per square centimetre, and in cast iron to 12,000, Half those figures, or say 63,000 per square inch for wrought iron and 35,000 for cast, is a good practical range.

Fig. 78.



Mitis metal, which is wrought iron containing aluminium, which renders it fusible, lies between cast and wrought iron, while steel containing manganese is completely non-magnetic.

971. *Curve of magnetization*; the facts are best shown in curves, of which Fig 78 shows several: 1 is that of very pure soft iron; 2, cast iron; 3, soft steel; 4, very hard steel. The dotted line shows what would be the line if B grew equally with H.

972. *Hysteresis.*—This is the name given to the energy lost in magnetizing and demagnetizing. It is strictly due to residual magnetism (Greek, to lag behind), the tendency of the particles not to return to the non-magnetic state. If a second curve be formed as in Fig. 78 by gradually lowering the magnetizing force, it will be lower than the rising curve, and the space between them measures the retained energy. This is a most important matter in connection with alternating current appa-

ratus, transformers, &c., as it is related to the "frequency" of the changes, and is higher in proportion with increase of magnetism. The wasted energy appears as heat in the iron.

973. *Foucault currents*, called also *eddy* currents, also heat the iron, and are often confused with hysteresis. They can be corrected by dividing the metal so as to prevent electric current forming: but hysteresis depends on the quality of the metal, and also increases with length and all the conditions which tend to retain magnetism

974. *Viscosity* is the name given by Professor Ewing to the theoretical cause of hysteresis manifested by a slow growth of magnetism, with a steady current; it is a familiar fact that to start a motion takes more energy than to maintain it; here it is supposed that the particles cling together: inertia may be sufficient without the added conception of cling, it causes the flatness of the curve of B with small H force; vibration, such as lightly tapping, facilitates magnetizing and demagnetizing by disturbing the cling, or inertia.

975. *Lag* is a name given to many forms of the effects of inertia, or retardation: it is the physical or molecular process which is the cause of hysteresis. It is evident that an effect must always *follow after* its cause, even though the interval may be inappreciable; thus current must follow E M F, and where these latter are variable and can be drawn as curves, the crest of the curve of E M F must always precede that of C. So the magnetism in a moving armature follows after the curve of H or force in the field. This also controls the position of the brushes in dynamo machines or motors.

976. *Phase* is a term given to the result of this "lag," which may be controlled to produce desired effects: thus, if an induced field, as an armature or a current, as shown in a curve, follows that of the inducer, their "phases" are said to differ, say by 90° when the "lag" is that of a quarter of the interval. It is by use of this that the problem of alternating current motors is being attacked.

977. *Leakage* in magnetism means the passage of lines elsewhere than in the useful field: thus in Fig. 25, p. 82, all the lines of filings between N and S are leakage lines because the theoretical magnet ought to exert all its force from its poles: therefore the smaller the air space of the true or useful field the less the waste in leakage. In a horseshoe magnet, the perfect form is a circle with field space cut out of it and its surface spread out, as in the horns of a dynamo, to enclose the working field, or armature: the nearer the arms are kept together lengthwise, the greater the leakage.

978. Magnetism is the same thing in permanent and in electro-magnets, and the same laws apply; but there are differences which must not be overlooked: in a steel magnet the internal forces or lines are a fixed amount; altering the circuit, as by means of an armature, changes the distribution but not the value of B. But in an electro-magnet the force, the value of B itself, varies by changes of the iron circuit, § 963; thus the holding power of an electro-magnet would be much greater than that of a steel one of the same shape and weight of iron, although they might be so arranged as to have equal action at a small distance.

979. These two functions, holding and drawing (called tractive and attractive forces), are quite distinct, and depend on different arrangement. Short magnets may give holding power, but length of iron is required to drive the lines to a distance, and § 141 explains the effects of polar distance. Joule contrasts a steel and electro-magnet.

Steel one attracted 23 grains, lifted 60 ounces.
Electro one „ 5·1 „ „ 92 „

For holding power the polar surface is the essential consideration, or in other words the cross section of the iron. Joule made electro-magnets carrying 175 lb. per square inch, and Shelford Bidwell has gone as far as 225 lb., but it is bad economy to go beyond 150 lb. for wrought iron, or 28 lb. for cast iron. This function is the starting point in designing magnets, as the other questions are, how to produce this limiting effect?

980. ELECTRO-MAGNETS.—These must be considered as consisting of distinct elements or parts, each having its own particular functions or laws to be examined apart from the others, while the sum of the effects is due to the combination of these for the utmost mutual action. These constituents are (1) the iron; (2) the wire; (3) the current.

The iron portion is divisible into (1) the core, the part upon which the wire is wound, which in a straight bar is the whole of what is usually called the "magnet": in a horseshoe, this is divided into two parts called the *arms* of the magnet; (2) the *base* or piece connecting the two arms, usually called the *yoke*; (3) the *armature*, which is truly a part of the magnet, though not usually considered as such: it is the agent in, and by which the magnetic force is manifested; thus the moving part of a dynamo is called its armature, because it is arranged to utilize the lines of the field between the poles of the field-producing magnets.

981. A straight core equally covered with wire throughout its length is equally magnetized throughout, except for leakage;

its two ends will be equal poles, and would lift the same weight. But if the wire is concentrated at one end, the core is no longer equally magnetized; its neutral point will be brought nearer to the wired end instead of at the middle: a strong pole and dense field will be produced at one end, and a weaker pole and more diffused field at the other end: the two ends will no longer hold the same weight, because the same number of lines of force will no longer enter the mass of iron to be attracted.

The *wire* is best distributed over the whole core where steady field is required: but where quick changes are desired the wire coil should be concentrated near the ends.

982. A horseshoe magnet is simply a bar magnet turned up so as to bring its ends into the same plane: the *strength of its poles* is not altered by this, but *their lifting power* is greatly increased, and the *permeance* being greater, the magnetism and strength of the poles would increase in an electro-magnet, § 978.

983. The *iron core* is the basis of all the considerations: the first consideration is the work the magnet is intended for, and this means either 1, the pull it can exert on an armature, its *tractive* force; 2, the pull it can exert on a distant armature, its *attractive* force; or 3, the nature of the *field* it is intended to produce.

984. The *law of traction* as defined by Clerk Maxwell is

$$\text{P (dynes)} = \frac{\mathsf{B}^2\,\mathsf{A}}{8\,\pi}, \text{ or P (grammes)} = \frac{\mathsf{B}^2\,\mathsf{A}}{8\,\pi \times 981};$$

or expressed in Pounds

$$\text{P (lbs.)} = \frac{\mathsf{B}^2\,\mathsf{A}}{11{,}183{,}000}.$$

The mystic $4\,\pi$ which appears constantly in formulæ is required only because of the old theory of "poles," the notion that magnetic force acts from a point, and according to the law of squares; these ideas are erroneous or purely conventional, but underlie the C G S unit system: $8\,\pi$ appears here because in a horseshoe there are two poles.

985. But a well-closed horseshoe closely resembles a ring, and almost all its lines enter the armature, so that B and N are practically equal, so the real meaning is that *attraction is proportional to the square of the number of lines entering the armature,* these depending, 1, on the force H, or ampere turns C *n*; and 2, on A the area, as well as on the permeability.

986. The *law of attraction* has not been defined. The old notion of inverse square of distance is exploded, § 141, and no

one appears to have yet found a substitute. It will not be easy to put one into a formula, but we may here see that the facts on which such a formula must be based are very simple, though apparently now indicated for the first time.

987. *Traction and attraction obey the same law;* both are related to the *number of lines which can enter the armature.* It is, as is beginning to be generally perceived, a question of the permeance or resistance of the paths open for the formation of "lines," and therefore mainly of air space or distance of the armature, as compared with facilities for leakage lines, § 977.

We have here a fresh evidence of the relation of energy to magnetism and electricity, for N^2 is the analogue of C^2 the work power of a current.

988. It is easy to test the number of lines which enter an armature in any position by means of an exploring coil of wire of known number of turns connected to a ballistic galvanometer, § 374. When the current in the magnet ceases, or the armature is suddenly pulled away, the current induced in the coil is a measure of the number of lines if the galvanometer is first standardized.

A similar process measures the distribution of the lines in a steel magnet by the application or removal of the armature: the current is greatest at the middle of a bar or the bend of a horseshoe, because there all the lines pass through the coil, § 961.

989. A *permeameter* for testing the quality of different irons can be made in the same way: the irons to be tested being all turned to the same dimensions, and used as cores to a small induction coil connected to the galvanometer, and comparing the deflections produced by a standard current. For testing the total capacity of iron, more elaborate instruments are needed, like those of Hopkinson and Thompson, which are intended to secure the utmost "permeance" in the iron by means of a closed magnetic circuit: but for practical purposes only the relative permeance is required as compared with that of a similar piece of the very best iron obtainable, which is the softest Swedish charcoal iron.

Curves corresponding to those of Fig. 78 can also be obtained by varying the primary current.

990. CONSTRUCTION.—The first consideration is the force to be exerted or field produced, i. e. N the number of lines to issue from the ends, § 979, and this is simply a function of A, § 957, the sectional area, not merely of the polar faces from which they issue, and which are often expanded into "pole-pieces" to direct the lines, but of the *core;* it depends upon, A the area, and μ the permeability of the specific iron used.

991. *Length of core* depends upon the space needed for winding on the wire necessary to develop the magnetic power; this space may be obtained either by lengthening the core or by increasing the depth of the wire space—an approximate proportion is that the length should be about six diameters; but the length depends also on the form of the field required: for mere holding power short cores with large currents are best; for action at a distance, longer cores, because each section, like a battery, adds power to overcome resistance, § 954.

992. *Hollow cores* are as effective as solid metal, provided the shell is sufficient to absorb the magnetic action of the current, but the ends must be closed with an iron plug of at least equal thickness. The best construction is to bore out the core to the required dimensions, and then slit it lengthwise down one side to prevent the formation of induced or Foucault currents when the magnetic state changes.

993. *The magnetizing force* required, § 960, depends on the quality of iron, as unit H is based on the permeance of air; therefore it will be $\mathsf{N} \div \mu$, and the question is really what C *n* (ampere turns) will furnish this?

994. The *magnetic strength* is proportional *to the current* passing, and to the *number of turns* of wire, that is to C *n*, subject to the conditions of § 971, that is, while magnetism remains proportional to current. Thus the same magnetic effect may be obtained from a few turns of wire and large current, or a small current and many turns, so long as the product of current and number of turns amounts to the same in "ampere-turns."

This is so because the same energy is conveyed by the wire. With a given weight of metal the resistance is as the square of the length, i. e. as the number of turns it can make. Current is inversely as this number; therefore if we have 1 ampere in 100 turns of 1 ohm R, the energy by $C^2 \times R = 1$ joule, then 1000 turns would have 100 R, and the current being ·1 we have $\cdot 1^2 \times 100 = 1$ joule as before. Here we see that magnetism is a function of energy; it is generated by energy *absorbed*, and follows the law of energy *expended* by the current.

995. *Every spire produces equal effect* in a closed ring, and subject to remarks, § 981, may be said to do so in all magnets, where the waste of lines through the air space is small. In other words, the magnetising effect of a turn is independent of its diameter: this is easily understood when we consider that *the length* of the acting current increases as its distance does, *and the* statement implies that the current is equal in both *cases.* Of course the larger spires offer greater resistance and

expend proportional E M F or energy: therefore the thickness of the helix should be kept as small as possible.

996. *Ampere turns required.*—This brings us back to the conception of the magnetic circuit, § 958: ampere turns generate H or magneto-motive force, § 960, and therefore replace the E of current formulæ, though H is the real analogue of E, just as N replaces current C, and reluctance R, § 965, corresponds to resistance, and therefore $\mathsf{H} = \mathsf{N} \times \mathsf{R}$.

997. But how are we to get the value of R? we have no units, like the ohm, to balance it against: it can only be calculated from the permeance of the circuit, § 963; this is only to be calculated from the permeability of the several parts of the magnetic circuit, that is, it is for each part, $\mu \times \mathsf{A} \div l$ (length), the same law as that of conductors, § 475. This is simple enough as regards the iron portion, but not so as regards the air spaces, where $\mu = 1$, but A is not very easy to estimate, unless the air space be very small.

998. But having estimated R either as the reciprocal of the total permeance or, directly, by inverting the formula to $l \div \mathsf{A}\,\mu$ for each part, and adding them together, H being $\mathsf{N}\,\mathsf{R}$, then by, § 960, $C\,n = \mathsf{H} \times l \div 1{\cdot}2566$ l being length of the magnet in centimetres. The division of amperes and turns is then controlled by the general conditions of the circuit, §§ 1003 and 1083.

999. A helix is simply a *space* measurable in cubic inches, or in the case of circular coils in cylindrical inches.

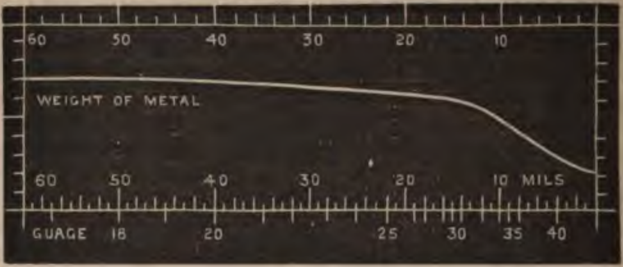
The *area* is measured, and in circles is as the square of the extreme diameter, less the square of the inner diameter, and multiplied by the length, gives the *space* in the measure desired, as in the case of wires, § 537: in fact we may regard the helix for the moment as a bar of copper of which we obtain the weight by multiplying by

per cubic inch 2247 grains, Log. 3·3516031
„ cylind. „ 1765 „ „ 3·2467447

1000. From this a deduction has to be made for space between the wires and for the insulating material, which will vary with each make. The best plan to ascertain the actual ratio is to make a mandril with recess sunk in it, of 1, 2, or 3 inches length for different sized wires; wind this with one layer of any wire and count exactly the number of turns contained. The diameter of the *bare wire* measured or calculated, § 543, will give the number of turns it would give, and the ratio of these numbers of turns will represent the space occupied by the *covering.*

Silk covering is more regular than any other, and I have obtained the curve of Fig. 79, from a number of experiments, as an approximation to the ratio of the weight actually contained in a coil to that of the solid metal, § 996, which of course is less as the size of wire decreases: the height from the lower line to the curve in parts of an inch will give a ratio by which to multiply the solid weight of § 996, to ascertain the actual *weight of metal in the coil*.

Fig. 79.



1001. This formula, given by Prof. S. P. Thompson in his instructive Cantor Lectures, will also give the information,

$$\text{ohms per cubic inch} = \frac{960,700}{D^2 \times d^2}$$

d being the diameter of the bare wire, and D that of the covered in *mils*.

1002. Wire Required.—The *size of the core* being determined by § 991, the *size of the helix* follows from § 996, and the *gauge of wire* to be used then depends upon the resistance adapted to the conditions, and varies with the nature of the work.

One limiting consideration is the permissible heating and consequent current density § 562: the heat, as a general rule, should not exceed 100° Fahr. over that of surrounding space.

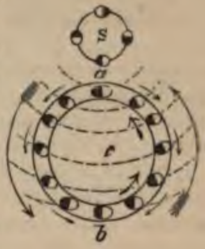
The *suitable resistance* of the E.M. is defined by the conditions of current supply, the general resistance of the circuit, and the available E M F: and these conditions also control to a considerable degree the thickness of the helix.

1003. Having the resistance required to be given, and the weight of metal at disposal, which is the weight of the wire giving the desired resistance, a rule-of-three sum gives weight *is to* 7000 grains as R is to ohms per pound, and a reference to the Table, p. 284, will show the suitable size. Or this may be calculated from the constants in § 544.

$$\frac{3{,}416{,}825}{\text{ohms per lb.}} = \begin{cases}\text{square of area in mils}\\ \text{of the required wire.}\end{cases}$$

1004. **Currents in Magnetic Fields.**—If we examine the actions upon the molecules of a conductor revolving among the lines of force of a magnetic field, as shown in Fig. 77, § 954, we shall see that different effects may be anticipated according to the direction of the motion; we shall be aided in examining the effects if we regard Fig. 73, § 945, as a vertical cross section of Fig. 77. If the axis of motion be in the central line, N S, and the motion takes place in the circles of Fig. 73, the molecules suffer no change of position as regards either their relation to S or to their arrangement in the moving wire; hence no effect can result. If the axis be lowered, it will be seen that each molecule, in order to retain its relation to the magnetic field, must in each semi-revolution swing half-way on its axis: this is shown in Fig. 80, which shows a ring of wire rotating on a centre *c* across the circles of the magnet S. It is obvious that the molecules of the wire, in order to keep their relation to these circles, turn on their axis in the direction of the small arrows, and in doing so set up a current in the wire, if a current really involves a molecular rotation. This *explanation* is, of course, hypothetical, but it is *a fact* that the motion of the conductor under these conditions does produce some action within the wire which results in an electric impulse.

Fig. 80.



1005. This, Fig. 80, is a very simple looking thing, but it is commended to the student as one of the very highest importance and involving the most essential principles of dynamo machines. Following Faraday, all writers speak very fully about "cutting lines of force"; they rest in that phrase, and no one thinks it necessary to give any reason *why cutting lines of force should generate a current* in the wire. This figure gives us the reason: the mere lines of force are nothing, *it is the rotation of the molecules of the wire while arranging themselves as parts of these lines of force that causes the current.*

1006. If a plate of metal is revolved under or above a magnetic pole, or between the poles of a horseshoe magnet, but below the middle line of the poles, as new sets of molecules are brought into action, sets of opposing currents are set up in the conductor, and can be collected by means of a pair of springs, one pressing on the centre of rotation, at *c*, in Fig. 80, and the other on the circumference at the points where the currents meet, which in the latter case is on the radius between the poles of the magnet, or at *a*, Fig. 80. This was the first form in which Faraday demonstrated the setting up of an electric current by motion of a conductor within a magnetic field. Some very striking developments of this action have been utilized by Elihu Thompson in America.

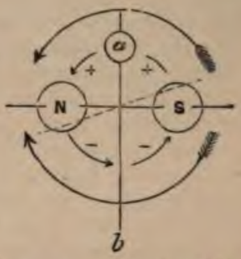
1007. The currents so generated have two effects: 1, they heat the metal according to the regular law of current work, so that with a powerful current metals may be made red hot and even melted; 2, they offer a great resistance to the mechanical motion; of course this resistance can never rise to the extent of stopping the motion, because then no current can exist, and it is in no sense an obstruction offered by *the field itself* which arrests the motion, but purely that the force which causes the motion is exerted *within the conductor*, producing electrical motion among its molecules, instead of setting up an external motion *of the conductor* itself. This effect is strikingly exhibited if we allow a silver coin to drop between the poles of a powerful electro-magnet; its motion slackens as it enters the field, it may take even two minutes falling across the field, and will be found strongly heated. We have in this experiment the clear evidence of how mechanical energy is converted into electrical currents by dynamo machines.

1008. If a bar of iron be surrounded by a helix of wire, a current of induction is set up when the iron is magnetized, and another in the opposite direction when it loses its magnetism; or the same effects are produced if a magnetized steel bar is inserted into and withdrawn from a helix. If a helix is wound upon the arms of a horseshoe permanent magnet, currents are in like manner set up whenever the armature is applied to or removed from the magnet; when a perfectly fitting armature of sufficient size is applied to a magnet the whole of the magnetic lines enter it, § 981, and the magnet becomes inert as to external action: in other words, the external field is absorbed in the armature, which closes the lines of force.

The removal of the armature requires the application of external energy sufficient to restore the normal magnetic conditions, and then the energy in the armature passes into the form of current in its wire, just as in the case of induction coils, as shown § 988. A little consideration will show that the action of dynamo machines is really a succession of such applications and removals of a solid armature, § 160.

1009. All the practical forms of magneto-electric machines are based upon some of these principles. The earliest and simplest form consists of an *armature of horseshoe shape* revolved across the poles of a horseshoe magnet. The wire is wound to form one continuous helix; the motion makes each end of the wire alternately + and −. We may, therefore, examine the action upon one end of the wire in a complete revolution. Let *a*, Fig. 81, be the end of one helix resting on the neutral line *a b* of the magnetic poles N S, and the line of motion be from *a* to N. North magnetism is being gained; and let us assume that the relation of the helix is such that this renders the end +. As soon as *a* passes N its north magnetism is being lost, hence the wire reverses its polarity; as soon as *a* passes the neutral line it begins to gain south magnetism, and (as gaining north makes it +) this gives it − polarity, which on crossing S, and when the south magnetism is being lost, again becomes +. We have thus four electric impulses which, being however in couples, resolve themselves, as may be seen, into two electric conditions, which, it should be observed, correspond to the states set up in the wire ring of Fig. 80. By means of a commutator on the line N S, therefore, a current can be obtained in one direction, though not continuous, but composed of the action of four distinct impulses. The mode in which the commutator acts is explained § 1058 and Fig. 93.

Fig. 81.



1010. It must be understood that the point of change is not *practically* upon the line N S, but upon a line in advance of it, as shown by the dotted line, Fig. 11. This is due to "lag," § 975: the line of actual break will depend upon the quality of the iron of the armature and upon the rate of rotation; it is even possible to conceive a rate of rotation such that no effect is produced at all, and in practice the motion cannot be advantageously increased beyond a certain rate, at which the maximum effect is produced.

A similar displacement of the neutral point occurs in all forms of dynamo machines, and the commutator brushes are made to move round the axis to some extent in order to admit of adjustment to suit the speed of rotation.

1011. It may be remarked here that each passage of the armature not only causes some molecular change in itself while taking *up magnetism*, but that it also causes a change in the molecular conditions of the magnet itself. If a wire is coiled upon a magnet, a current will be set up in at each passage; in fact, many apparatus, such as fuse-exploders, are constructed upon this principle; the poles of the magnet themselves are wound with wire, and the current is produced by applying an armature and forcibly withdrawing it, § 1008.

1012. The changes of the magnetic field may be tested by a telephone based upon a soft iron bar, which being applied to the magnet will be magnetized strongly when the armature is distant, and less as the external lines concentrate in the approaching armature; at each such change there will be a sound. The efficiency of any armature may be tested by the reduction it produces in the external field, as shown by the diminished deflection upon a magnetic needle at a little distance.

1013. DYNAMO-ELECTRIC MACHINES.—These modern generators of electric current have assumed so many forms that it would be imposible to enter at all fully upon their history, principles, or construction in the space at command. Therefore only the general principles will be considered in a form to be of most interest generally, and readers having special interests will do well to refer to works on this subject; thus amateurs who wish to make dynamos will find the work of Mr. S. Bottoné meet their needs, and manufacturers or seekers of large machines will study those of Prof. Silv. Thompson and Mr. Gisbert Kapp, and articles in the technological periodicals.

1014. They used to be classed as *magneto-electric* and *dynamo-electric*, the early forms having permanent steel magnets; but this is only a matter of construction and growth of knowledge. All consist essentially of two systems.

1. The *magnetic field*, which may be produced either by steel magnets or electro-magnets, but which it is desirable to make as powerful as possible.

2. The *armature*, which takes up the force of the field and by its agency transforms the energy supplied mechanically into electromotive force and current.

1015. HISTORY OF DYNAMO MACHINES.—Faraday obtained a current from a magnet in 1831; the next year Hippolyte Pixii of Paris produced the first machine for doing this practically; it consisted of an electro-magnet, under the poles of which a powerful steel horseshoe was rotated by a shaft; this resulted in alternating impulses, and a commutator, composed of two pairs o half cylinders with springs, exchanged the relations of the wir ends to the two terminal binding screws, so that these delivere a current always in one direction.

It will be seen that this machine, rough and imperfect as wa its construction mechanically, yet contained all the necessary elements, and carried out the essential principles of the conversion of mechanical energy into dynamic electricity.

1016. Saxton of Philadelphia reversed the construction of Pixii's machine in 1833, by fixing the permanent magnet and rotating the armature, which, while in no way altering the principle, simplified the construction, and did away with one pair of contact springs in the commutator.

1017. Clarke of London, in 1834, still further modified the construction by fitting the magnet in a box and rotating the armature over the side of the magnet instead of across its poles. This is the instrument still well known in the shops as the "medical magneto-electic machine."

Pixii's, Saxton's, and Clark's machines are merely modified forms of one *type* or principle, and as it is so well known I shall refer to this in future as "the Clarke type."

1018. J. S. Woolrich produced the first practical machine for large currents and engine power in 1841; it was practically a compound Saxton machine with many magnets on a frame, and many electro-magnets rotated by an axis (thus greatly resembling the later Alliance machine), and it gave great pleasure to Faraday, who saw in it the rapid growth of the scientific infant he had presented to the world ten years before.

1019. The next progress was made in 1856 by C. W. Siemens, by the device of his ⌶ core or armature, § 1058, by which the loss of power in churning the air is minimized, as it enables a long magnetic core, with short polar distance, to rotate in a very intense "field" with the greatest useful velocity, and yet with little momentum or mechanical stress. This I shall refer to as the "Siemens' *core*" in order to distinguish it from the *armature* of his later machines, which constitute a different type.

1020. H. Wilde made in 1867 a simple yet a very ingenious combination of two Siemens' machines. He used a Siemens' machine with permanent magnets, but instead of using its current for work, he directed it into a second Siemens' machine with a large electro-magnet for its field, so as to obtain an intense magnetic field: the core which rotated in this therefore generated a much larger current, while of course requiring proportionate energy to drive it.

1021. The next advance, also a very simple one to our now extended knowledge, laid the foundation for all the later forms of machine. In the latter part of 1866 Mr. S. A. Varley, Professor Wheatstone, and Dr. Werner Siemens simultaneously carried the idea of *accumulation* a stage further than Wilde, who depended on the current derived from one permanent magnet to generate a stronger magnet. The new and fertile conception was, to commence with the very weakest magnetism, and make it generate the strongest, in fact to make *the electro-magnet magnetize itself*, by sending the current from the armature into the coils of the field magnet, each in turn reinforcing the other, till the maximum of magnetism was reached, starting from the small residual magnetism always present in iron once magnetized. The curious thing is that Mr. Varley had a pre-emptive right to this idea, because it was simply transferring to the new field the principle he had before applied to his static accumulator, § 58, yet it was years before his part in the matter was recognized, though he had actually patented the principle before the other co-discoverers who got most of the credit had mentioned the subject.

1022. It should be mentioned here that glimpses of the idea of accumulation had been perceived by others; Millward of Birmingham in 1851 suggested the causing of the electro-magnets generated by the current to pass over permanent magnets so as to sustain their force. But Stephen Hjorth in 1855 clearly anticipated Wilde's combination of two distinct machines by producing the same effect in one. A rotating ring of armatures, similar to that of the Alliance machine, passed between the poles of a massive horseshoe magnet; the current thus generated was taken up by a commutator and passed into a pair of large electro-magnets, between the poles of which the ring of armatures also passed, and generated currents to be applied to work.

1023. Mr. Ladd devised several convenient machines for utilizing the principle of accumulation. He made large electro-magnets of boiler plate fitted with pole pieces between which Siemens cores rotated. In some he placed such pole pieces at each end of two straight magnets with a core in each, one serving to maintain the magnetism as in Wilde's machine, and the other for the work. In others there was a polar system at one end of a horseshoe magnet, but the core consisted of two parts fixed at right angles to each other so as to come into action alternately, the two parts serving the same purpose as the separate cores of the other form. These machines were therefore identical with Siemens', but with the electro field-magnet instead of a permanent magnet.

1024. The *Alliance* machine should be mentioned in the order of development, though it introduced no new principles. It consisted of a ring or disc carrying near its circumference a number of straight or bar electro-magnets arranged parallel to the axis, which were carried by the disc between the two poles of stationary steel horseshoes arranged on a frame, and equal in number to the armature bars. A number of these discs were mounted on the axis with corresponding field systems around them constituting a compound Clarke type of machine very similar to that of Woolrich. The most important result of this machine, which was used for generating light, was the discovery that it was not necessary to *commutate* the currents for this purpose. The machine was a failure at first, because of the difficulty and loss at the commutator, but answered well when simple collecting cylinders and springs were used, and the alternating current sent to the arc lamps.

Holmes' machine, which was simply an Alliance, was patented in England in 1856, and in 1862 was used at the Dungeness Lighthouse, the first successful and permanent use of the electric light in England.

1025. So far, all the machines were of the Clarke type, consisting of an armature of constantly reversed polarity, producing alternating currents, which had to be directed to the circuit through a commutator. In 1860 Dr. Pacinotti of Florence conceived the idea of a *continuous ring* rotating in the magnetic field, with the induced magnetic poles always fixed in one spot, though the iron in which they existed was being constantly changed, and fresh coils of wire brought under their influence, § 1064. It was really devised as a *motor* to be driven by batteries, and the principle of accumulation which was destined to make it a good generator of current was unknown when in 1864 the invention was described in the *Nuovo Cimento* and several small machines made and deposited in the Florence Museum.

1026. Z. T. Gramme of Paris re-invented the Pacinotti plan as a generator in 1870, and his machine was used in electro-metallurgy. Von Hefner Altenech, of the house of Siemens and Halske of Berlin, modified the rotating armature in 1872. From these two types of armature, the *Gramme ring* and the *Siemens drum*, all the modern forms of dynamo-machines originate: to follow them out and describe them would need a large volume and a very special acquaintance with the subject. But there is a mode of following out the principles, perhaps even more useful than tracing the forms in which they have appeared.

1027. Evolution.—The doctrine or idea of evolution is now firmly grafted upon the scientific mind, and is extending itself into all the departments of knowledge. It teaches us that nothing is isolated; every fact, every idea holds some relation to others from which it grows, while it becomes a point of origin for others, sometimes continuing a direct line, sometimes constituting a point of differentiation, at which may originate several growths, proceeding onwards until there appears no relationship between their products. Such is the relationship among the various languages of mankind, as well as among the races of beings. Now, an important effect of this is that not only may the untrained mind be unable to see a connection between two apparently distinct things, but that there may actually exist *gaps in the line of evolution*, missing links in the chain, either lost, or which never had actual existence, except in the rudimentary condition.

1028. In chemistry we have a number of "homologous series" and groups of series, which illustrate this very remarkably. Thus we have a series of radicals starting from methyl CH_3, and rising by additions of CH_2 through a long line of substances, which gradually become denser; the addition of hydroxyl HO to any one of these substances converts it into a corresponding alcohol, such as the commonly known alcohol, the hydrate of ethyl, C_2H_5OH, and glycerine, not commonly considered alcoholic in character, yet really so scientifically. Another atom of oxygen inserted in the molecule, in place of H_2 gives us the corresponding acid, such as the acetic acid of vinegar C_2H_3OOH, up to stearic, and the waxy acids and so on.

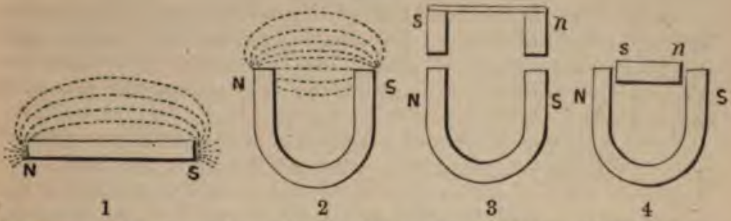
1029. The same groups and substances may be classified upon other systems, such as that of types, but still with the same results which are now under consideration, the construction of connected lines and diverging groups, forming a clearly connected whole, in which, however, there are many gaps—substances which do not actually exist in nature, or have not been discovered, but the possibility of whose existence is evident, while some of them have actually been produced artificially in consequence of this foreseen potentiality of existence.

1030. EVOLUTION OF THE DYNAMO.—It is such a relationship that I wish to present among the different kinds of machines not as a matter of fact, not as implying that the inventors o the different forms actually developed them in this manner, bu as essential to the understanding of the resemblances and differences among the machines, and as enabling workers to proceed upon definite principles, rather than upon rule-of-thumb processes, and costly tentative experiments.

In the endeavour to realize such a systematic conception, the first thing in development of correct ideas is to clearly distinguish between *things* and *appearances*, between fundamental *principles* and mere forms of construction.

1031. To begin with, we should recognize that there is no real difference between a bar magnet and a horseshoe magnet, except in the form of the *field of force* set up between the poles, which adapts one form to some purposes and the other form to others. Thus it is evident that 2, in Fig. 82 is merely 1, with

FIG. 82.

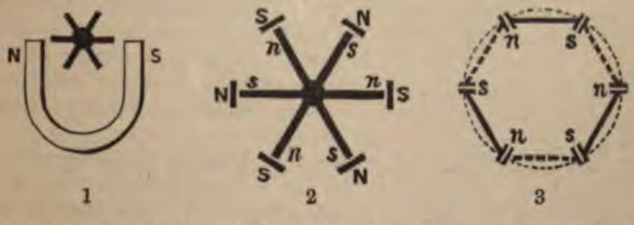


its two ends turned up by bending the middle, which allows the lines of force connecting N and S to be shortened, the resulting field to be reduced in area, and consequently increased proportionally in intensity.

1032. It is less obviously, but equally true, that a horseshoe armature rotating over the poles of a magnet, as in Saxton's machine, or across the poles, as in Clarke's, acts precisely as does a straight bar electro-magnet passing between the poles, as in the Alliance and other machines: thus 3 and 4 differ in no way in type and action; nor do the Clarke and Alliance machines; the differences relate to mechanical construction, and to the most effective way of taking up the lines of force of the magnet. In all these forms the action is merely the placing of the iron of the armature in such position as will concentrate within its own mass as much as possible of the external field of the magnet and diminish its independent external actions.

1033. *Compound Armatures.*—One stage of evolution from the

FIG. 83.



mere bar is a radial armature, which Fig. 83, 1, shows is merely a multiplication of the bars of Fig. 82, 4. Its rotation in the plane of the poles N S, instead of across them, as in the disk armature, is a pure matter of construction, and this gives us one of the Lontin machines, which is built of a series of such radial systems, slightly overlapping each other, so that the field is transferred into one after another of the collection of bars which constitutes the complete armature.

1034. *Multiple Field.*—Another step combines the single ring of radial bars of Fig. 83, not with a single field magnet, but with an equal number of alternating field poles. We have then the conditions of the Alliance type, different as the machines appear. If we look at 2, this is evident. It is of no consequence as to theory how the several poles N S of the field magnets are related; those at opposite points may complete the horseshoe, and then the two radii of the armature constitute a straight bar between its poles. Or adjoining poles N S may form a separate field magnet; then the two adjoining radii form its armature (all being supposed to unite at the middle), and constitute a horseshoe.

1035. *Apparent Ring Armatures.*—This leads to a new stage of evolution, which develops an apparently distinct type, still depending on the same principles. We know (§ 1031) that a straight bar and a horseshoe are the same in principle. We take, then, each adjoining pair of radii, acting as a horseshoe, and straighten them into a bar armature to the adjoining poles N S, and thus we develop the three bars of Fig. 90, 3, and with three more added as shown in dotted lines, and then curving the bars as also shown in dotted lines, we have what looks like a ring armature, but is so only mechanically. Electrically, it is a hexagon system of independent armatures, arranged in pairs so as to divide the forces of the field poles between them, and form a succession of consequent poles in the ring thus constituted.

1036. This is, however, an important stage of the evolution for it is the basis of three machines wholly distinct from eac other. (1) Fig. 83, 3, as rounded off, gives us the principle the De Meritens machine; (2) is the armature of the Lonti § 1033, with multiple fields, and in its hexagon form; (3) is th elemental ring of the Bürgin machine, often, but wrongl described as a compound Gramme machine. The fact that th Bürgin armature is constructed of a continuous iron ring only a detail of manufacture: theoretically each segment is independent bar-magnet, fitting to, and polarized by, the e tremities of the field magnet poles. (3) As a ring, and as *continuous* metal core, gives us the Brush armature, which *really* composed of independent electro-magnets, and in so far different from the true continuous ring of the Gramme type; it does, however, approach a stage further towards it, by a continual interchange of sub-segments successively building up the actual bar, and by reverting to the bipolar field system.

1037. *True Ring Armature.*—At the next stage of evolution we pass from the *apparent ring* of Fig. 83, 3, to the true ring of the Gramme or Pacinotti type. In all the preceding forms independent poles have been created and reversed completely, and the wire of each segment has its independent alternating impulses, set up in and collected from it. But the essence of the true ring is that while, structurally, the iron core rotates and the iron is continually changing its magnetic state, the *true core*, the receiver of the lines of force of the field magnet is stationary. This armature is studied § 1066.

1038. The *Siemens drum* armature resembles the Gramme in this respect; in it also there exists a stationary magnetism in the internal mass of iron, produced by the induction of the fields poles: we may compare it to Fig. 83, 3, and conceive that the wire of the drum alone moves in the space between the poles of the field magnet and those of the induced armature, § 1063, 3.

1039. *Wires and Magnets.*—This brings us to another line of evolution which appears to be distinct, and yet is of the same order. The action of wires crossing lines of force appears to be of a different nature from that of wires wound upon a bar of iron temporarily magnetized; but the currents produced in both cases are due to the absorption of external energy, and to the rearrangement of the molecules of the wire while adapting themselves to the lines of force which they momentarily occupy; the difference is that in one case the wires form part of the magnetized system itself, and in the other they temporarily form part of an independent system.

1040. *No particle of matter is independent*, and this is a fact little dwelt upon, but of such importance to all true thought, that it should be thoroughly realized and firmly grasped by the mind. Nothing exists for or by itself; every atom of matter is in the place, and under the conditions it occupies, as a result of the sum of the various forces which influence it. This is most wonderfully evidenced by the infinitesimally instant changes which we have been enabled to trace out in many forms of matter, as resulting from rapid intermittence of light and heat.

Thus, in a wire, each molecule is constituted of two atoms, held together (probably through the agency of polar forces corresponding to those of magnetism, and commonly attributed to differential charges of + and − electricity) by the force called "chemical affinity" or attraction, which force is, as shown, § 625, closely related to electromotive force. The mass of the wire is held together by similar forces of molecular attraction, crystallization, and cohesion. All these forces imply energy stored in the matter, and they are modified from moment to moment by heat and other external forces.

The actual arrangement of the particles of the wire is the combined result of all the forces influencing them.—These particles are simply in a condition of equilibrium liable to instant change.

1041. Such a change occurs the moment these particles enter a "field of force," the energy of which is charged upon them, and introduces new conditions of balance. The excess of force, the new stresses set up against the pre-existing forces, involve an expenditure of energy in effecting molecular changes, and we have the conditions described, § 606; the potential energy of the lines of force in the field becomes kinetic in the wire, and therefore develops E M F, and, by effecting motion among the molecules of the wire, generates an electric current, according to the arrangement of those molecules—the number of conducting chains which they can constitute, § 464.

Therefore, in order to generate a current, the wire must traverse a field in such a manner as to continually change the arrangement of its molecules among themselves, and their relation to the sum of the actions exerted upon them; mere motion in a field may produce no effect whatever.

1042. When a bar magnet is inserted into a ring of wire carrying a current, a reaction occurs between the two fields which, if concordant, tends to unite them into one, and to place the two centres of the fields together; if discordant, that is if the lines of force are not in the same direction, a sort of conflict occurs for the possession of the matter in which the lines of force exist. In the first case we have *attraction*, and the ring of wire moves to the middle of the magnet, in the other we have what is called *repulsion*. The current in the wire is also either increased or diminished during the action, § 1050.

1043. When a bar magnet is inserted into a ring of wire, not occupied by a current, it sets up a momentary current therein, opposite in direction *to the proper magnetizing current of the bar*; a mechanical resistance is experienced, and the ring is for the moment repelled: these actions are examples of Lenz's law, § 950. But it is not enough to quote a law, we should realize what is the cause and the process: the wire becomes a part of *the external* field and lines of the magnet, and has to arrange its *molecules* accordingly, as shown Fig. 31, p. 89, while a magnet izing current is part of the *internal* lines, an integral part of the magnet, and its molecules are ranged to correspond, as in Figs. 74, 75, § 951.

1044. To make these mutual reactions intelligible it may be well to develop a little the considerations presented, §§ 944–53. In Fig. 71 we have a section of a current, showing radial lines of force, upon which magnets place themselves tangentially; those radial lines may perhaps be regarded as sections of the lines of static electric induction, springing from all parts of the circuit towards all other parts, and resolving themselves into a sheath of lines of static stress, parallel to the conductor. Magnetism and electricity are related to each other, their planes or lines of polar order and force being at right angles to each other, § 130. We may, therefore, expect some magnetic force to exist at right angles to the lines of conduction, and such exists in the form of rings surrounding the conductor.[*] Not only do magnetic needles place themselves in these rings, but the rings themselves may be made visible. If we pass a current-carrying wire through a card on which iron filings are sprinkled, and tap the card lightly, the filings arrange themselves around the wire, thinning away as distance increases; they are, in fact, temporarily magnetized and unite lengthwise to form closed rings around the wire in the lines of equal magnetic force. It should be clearly understood that these rings have no polar actions or attractions; they resemble a closed steel ring which may be strongly magnetized yet have no apparent magnetism, because it is a completely closed field; at every section there is an equal N and S pole existing and combining together. It is true that a piece of iron, such as a filing, enters the ring and does then possess two poles, because its *capacity* is greater than that of the air; but these poles are purely *within the ring*, they exert no external actions because the iron is not an independent magnet, but only a part of the external lines of the wire and therefore its poles are related only to the wire. Fig. 84 is intended to convey this idea of a conductor: 1 is a perspective view, A being the conductor, and the arrow shows the direction of the current. B and C are two rings of magnetic force consisting of molecules polarized under longitudinal forces, shown by the dotted lines connecting the circles B C, these lines representing the stress due to difference of potential set up in the polarized chains constituted by static electric induction of which one chain is shown connecting the rings. Fig. 27, p. 84, represents one of the molecules in such chains lengthwise, while the horizontal arrows shows its magnetic lines. The other parts of Fig. 84 are sectional views showing a ring B C, of which 2 shows the molecular construction, and 3 conveys the idea of the lines of magnetic constitution.

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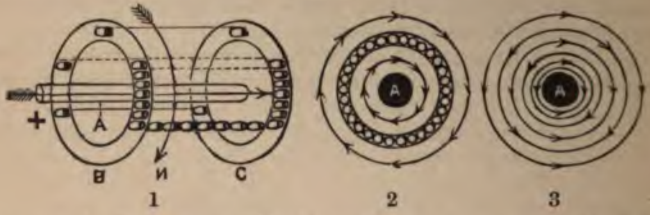
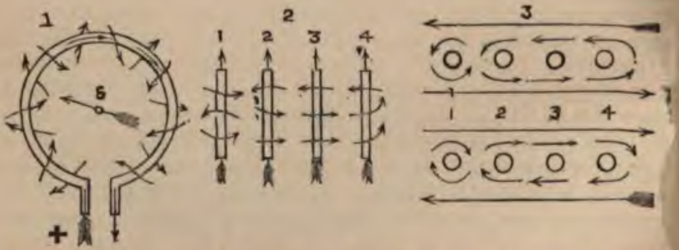
[*] It should be noted that these known *stress* lines, longitudinal and circular, treated here as was universally believed till recently, as generated from the wire, are now used as the hypothetical agents for transfer of energy to the wire and production of current *in* the wire in the pseudo-orthodox theory fashionable *among the Professors*, § 466.

FIG. 84.



1045. A closed magnetic ring when cut across manifests true poles at which the forces are concentrated, and a similar effect can be produced on the circular lines of force around the conductor. This happens, in fact, when a wire is wound into a helix, forming a series of wires side by side, as is shown in Fig. 85: this is no mere fancy, the iron filings prove its truth if we pass several wires side by side through a card as before. Fig 85, 1, shows the conditions of a single ring of wire, the unit turn of a helix—in fact it is the conductor A of Fig. 84 turned into a ring so as to bring all its lower side into the inner part; then

FIG. 85.

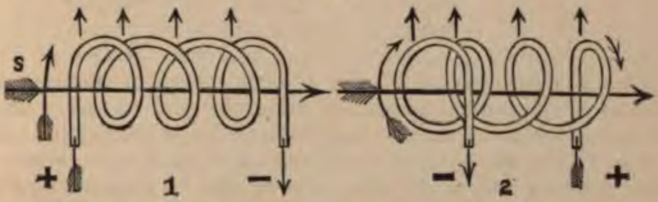


it is evident that all its rings of force tend in the one direction internally, and in the opposite direction externally: the internal arrows show the resultant magnetic action, as though these rings of force constituted an internal vortex.

1046. A series of such rings, placed side by side, is shown in Fig. 85 in vertical section at 2, which represents the further or left-hand side of the rings as looked at across the interior. It should be noted that the change in direction of the small arrows from those of Fig. 84 is the result of looking at them from opposite sides, and is evident in all three portions of this figure. In 3, which is a horizontal section of the helix, we see that the circular lines of force of the adjoining wires conflict as they enter each other, and are therefore broken up into their internal and external halves, which then unite to form lines of force along the whole of the wires.

1047. Fig. 86 shows how different ways of winding wires bring these principles into action, and it should be compared with Figs. 74 and 75, § 951, which deal with the same subject in a different manner. 1 is a right-handed helix in which the current gives S magnetism inside it, in accordance with the following law: *A current moving as the hands of a watch gives south polarity on the side from which it is looked at*, and *vice versâ*. It also gives N polarity on its outside. A left-handed helix is shown at 2 with the current reversed in direction so as to give the same polarity as 1, and it therefore really represents the wire of 1 continued to be wound, outside the first layer, in the return direction. In this way it is evident that the current is really running *in the same direction in all the wires which run in the same direction*, so that all the inductive actions are united.

FIG. 86.

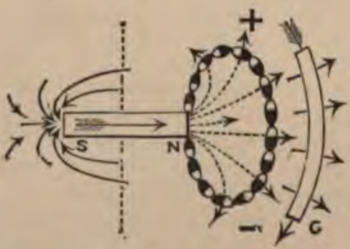


1048. These helices also show how such a reverse winding upon compound armatures of any of the forms of Fig. 83, brings all the alternately reversed actions of each segment into a current of one direction throughout, so that only one pair of commutator springs is needed to collect the alternate currents into one: but such a commutator would require as many alternating strips as there are sections, in order to effect the change as each polar change of magnetism occurs. Such a commutator resembles that of the Pixii machine, § 1015, being composed of a pair of cylinders with alternate spaces cut away so as to constitute a crown wheel with a tooth for each magnet pole, so spaced that the two can interlap: the cylinders are connected to the wire ends and springs pressing on them take the currents always of one direction to the terminals.

In machines of the Siemens core type, § 1055, needing only two segments, the teeth become half cylinders, which are so formed that the division is slightly diagonal, as shown at C, Fig. 93; this avoids complete break of circuit and diminishes burning by sparks.

1049. In § 1044 and Fig. 84 it is shown that, as a consequence of linear electric stress, there are formed rings of magnetic order at right angles: then we must expect from the normal relations of electricity and magnetism that lines of magnetic stress, such as are formed in the magnetic field, should be attended with rings of electric polarization forming sections of the field: this is the effect shown in Fig. 31, p. 89, and in Fig. 77, § 953; then, treating the electric stress as being the active cause of the differential arrangement of the + and − ends of molecules, the electric rings must consist of molecules end to end, while the magnetic rings consist of molecules side by side, with the electric lines passing through them. It is desirable to clearly realize this now in order to trace the action which occurs in a wire when it enters a magnetic field.

FIG. 87.



1050. Fig. 87 represents a bar magnet N S with one of the rings of electrostatic order formed on the lines of force issuing from its north pole. C is a conductor carrying a current, such as the ring of Fig. 85, 3, and shows how its magnetic lines agree with those of N S, the result of which is to draw the wire *to the* middle line of the magnet where the sum of the agree*ments is* greatest: in these conditions the current and magnet *unite, § 1042*; the space within the wire becomes part of the magnet, and the return lines of force are deflected to the outside of the wire where they also agree with its lines. But if there were no current in C a different set of conditions would come into play. The full field cannot be drawn so as to be intelligible, but a little consideration will show that the space is filled with such circles as that shown, of all diameters; therefore the wire, as it approaches the pole N, will be continually entering fresh circles, with their magnetic lines in different directions, so that its molecules will be solicited in constantly changing directions in order to accommodate themselves to these changing conditions, with the result shown, § 815.

1051. In Figs. 88 and 89 we can see what happens when a wire crosses the lines of force of a magnet. In Fig. 88 we have a vertical section of the field between the poles of a horseshoe, or those of a dynamo machine, showing the *lines* of magnetic force and the resulting electric *rings*; Fig. 89 is a section of the same field, in which we can see what occurs in a wire traversing it in the direction of the arrows: as it occupies the several vertical dotted lines, it cuts circle after circle, in each of which there is different angular relation to the wire, which would result in a rotation of the molecules in a spiral line around the wire; here we have the explanation of what occurs in armatures of the Gramme and Siemens types.

FIG. 88.

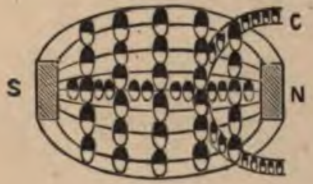
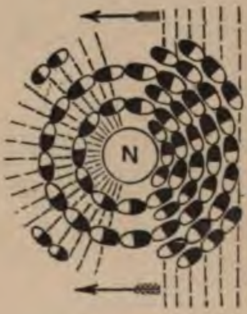


FIG. 89.



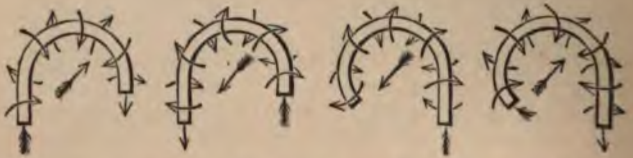
1052. Such a field between two poles may be regarded as a bar magnet, without return or external lines. Therefore when a helix occupies the field its wires correspond to the several circles shown, and the molecules must form a continuous chain corresponding to these circles, and in taking up that position a *similar spiral rotation* is necessary.

If the helix contains an iron core it concentrates the lines of force more speedily and more completely, so that Fig. 88 shows us what occurs in armatures of the types of Fig. 83.

If we consider the action of a ring descending vertically upon N we have a modification of § 1049, and a more full idea of the action on the wire: this is shown at C as again a spiral rotation of the molecules, resulting from their relations to the different circles into which the different parts of the wire enter.

1053. CURRENT AS A SPIRAL MOLECULAR ROTATION.—The actions thus presented indicate that electric current is not propagated in a direct line along the conductor, but in a spiral round the conductor, see § 912. Such a spiral progress of apparent linear motion is found in other cases: in a vibrating metal rod giving out a musical note, a loose ring of paper comes to rest on the nodal points of the vibrations, and these form a spiral line around the bar; the phenomena of polarized light indicate that the undulations take place in all planes, which corresponds to a spiral propagation, just as a corkscrew looked at edgeways appears as an undulatory line and is really such an undulation in all planes. Professor Hughes's examinations of the phenomena of magnetism, indicate the existence of this spiral molecular arrangement, rather than a direct linear polar order of the molecules. The subject is not ripe for very definite opinions, but I offer Fig. 90 as suggestive. Assuming that a "positive" current implies a right-handed rotation in the wire, we have an obvious cause for the direction of the magnetic circles corresponding to it: for this purpose it is of no moment which may be the actual direction corresponding to the + current, because our making the point of the arrow correspond to N magnetism is purely arbitrary.

FIG. 90.



By reference to Fig. 86 it will be seen that 90, 1 and 2, are the front turns of a right-handed helix with the current in the two *directions*, while 3 and 4 are the same for a left-handed helix *1* and 4 also show why a right-handed helix is the same thing as a left-handed helix at the other end, with current reversed and therefore the same magnetic actions: 2 and 3 show the same, as they are exactly alike except that the beginning, or longer end, is exchanged.

1054. THE FIELD MAGNETS.—These are now made in a great variety of forms, some long, some short, some straight, and some curved; all this relates to details of construction, variable with the ideas or the fancy of the maker, but they are all, in principle, horseshoe magnets. In the early machines with steel magnets, they were of the simplest form; later on double horseshoes forming common poles in the middle were generally employed. Fig. 91 shows the usual Gramme type, and Fig. 92 the form employed by Siemens.

FIG. 91.

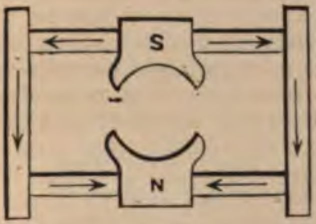
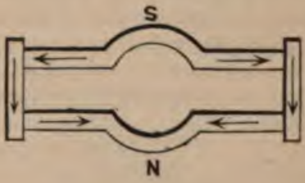


FIG. 92.



The single horseshoe fitted with pole pieces is now most in favour, and sometimes it is mounted with its pole pieces downwards in the neighbourhood of a massive base plate of iron which tends to draw the lines away from the armature. The base plate may properly form the "yoke" of the magnet, as the lines of force do not issue there, but no iron ought to be allowed in the vicinity of the poles, and more especially it ought not to be near both poles. It would appear that the double horseshoe of Figs. 91, 92, should concentrate the field upon the armature space better than the single form of Fig. 98, but the cost of construction may be greater.

1055. ACTION OF FIELD MAGNETS.—One of the principal elements of the E M F of machines is the "intensity of the field," the number of "lines," § 964, traversing the armature space, different systems of supplying the field magnets are employed. In the original machines, with permanent magnets, this element is comparatively fixed, and therefore the E M F generated depends upon its other element, the angular velocity of the armature, or the rate at which the wire traverses the lines: therefore in any given machine of this type the E M F is propor-

tional to the speed of rotation, so long as the intensity of the field is constant. The same law applies to electro-magnets fed by an independent source, such as a separate machine, or a distinct armature. This last plan is not quite so regular as the others; because the field magnet is itself modified by the reactions of the armature, as are its several relations to two or more armatures. Even with permanent magnets a disturbing action occurs: poles are induced in the armature by the field magnets; in some forms, polarities are also induced by the current in the armatures, and this varies with the external resistance: such causes modify the intensity of the field in practice. In the ordinary machines the conditions of the field are controlled by different modes of winding and of distribution of the feeding current as explained § 1076.

1056. *Displacement of the Field Poles.*—The axis, or direction, of a magnetic field of force, is of course the straight line between the poles, and the central polar focus of such magnets as Figs. 98, 99 is obviously the middle of the iron; but this is no longer the case when a rotating armature is in the field. Two actions then occur, which distort the normal conditions. (1) The wires themselves, carrying currents, have affinities with the lines of force in the field, and act upon them just as a moving body does upon a liquid, so that the lines of force instead of lying in the normal position of the field, are drawn aside in the direction of rotation. (2) The iron of the armature does not attain full magnetism until it has passed the focus of the pole, because it takes time to magnetize, § 1021. But the pole formed in the armature attracts the field pole, and as the polar position is not fixed in a mass of iron, § 150, the field pole itself follows the armature pole, and the polar line of the field magnets is no longer symmetrical, and at right angles to the line of the magnet, but is drawn forward in the direction of rotation of the armature, as shown Fig. 81, § 1009.

1057. As a consequence, the neutral points of the armatur itself are no longer on a central line, but are moved forward i the direction of the rotation to an extent variable with th currents passing, and altering external resistances. This neutra point is that at which no E M F is set up in the wire occupyin it, and therefore it is the position at which the collectin brushes must be set. If the brushes are on either side of th neutral point, the local E M F sets up currents resulting i sparks at the brushes; a certain amount of "lead" has there fore to be given to the brushes, and a power of adjustment, b moving on an axis, to compensate for changes in the neutr line.

The proper position of the brushes is a principal distinction between dynamic generators and motors, as in these latter, the current being supplied from without, sets up an entirely different reaction between the polar positions of the field and armature.

1058. SIEMENS' CORE.—This, mentioned § 1019, is shown Figs. 93, 94: A is a solid soft-iron mass, of a section resembling that of an H girder, with the faces turned down to arcs of a circle. It is now generally built up from thin sheet iron punched to the proper shape and strung upon an axis fitted with a shoulder near one end, and a screw nut at the other to press the sheets together: if the stampings are made with one end only of the form shown in the middle of Fig. 94, and strung alternately on the spindle, there will be air spaces formed in the poles which keep the armature cool without much affecting the magnetic capacity.

FIG. 93.

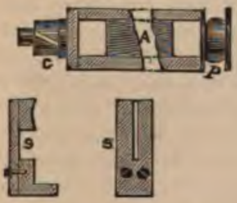
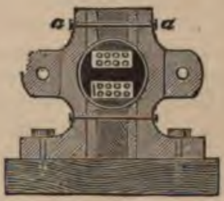


FIG. 94.



The wire is wound longitudinally, as shown in section in the middle of Fig. 94. The coil may be covered with a sheathing of wood so as to form a solid smooth cylinder, with grooves in the face to contain fastenings to hold the wood in its place. On the ends of the armature, brass plates are securely screwed to form the axis of rotation, and carrying at one end p, the driving pulley, and at the other end the *commutator*, c. This consists of a cylinder of ebonite fixed upon the axis, upon which are secured the two halves of a gun-metal cylinder, cut diagonally, as shown; the ends of the wire of the armature are led through the end pieces and secured to these. Frequently, one of the connecting pieces is fixed to the axis, and one end of the wire to the armature instead of isolating both. Springs like s, fitted with a turned pad of steel or other metal, press upon the cylinder, and take up the current, or brushes of wire may be used.

1059. *The Siemens core* is used in a variety of small motors, sometimes with permanent field magnets, and sometimes with electro-magnets, and a slight change of form is considered to improve the action; either the field space is changed by allowing each pole-piece to partly overlap the circle, or the core itself is made slightly elliptic; in either way a gradual approach is made by the armature instead of its at once coming close up and maintaining a constant space between the faces of armature and field poles.

1060. The *field magnet* pole-pieces only are shown in Fig. 94; *a*, *a*, are two blocks of cast iron of such length as may be required, separated by blocks of wood or other non-magnetic substance, and bolted together by brass or copper fastenings; a cylindrical opening is bored through, in which the armature, Fig. 93, rotates. At the proper intervals there are lugs, as shown, to which are to be bolted the actual magnets, either steel or soft iron, as required: *a*, *a*, form, in fact, the poles of a compound magnet, and may be made in separate pieces for each magnet; all surfaces in contact with the true magnet being carefully faced so as to secure a large surface contact.

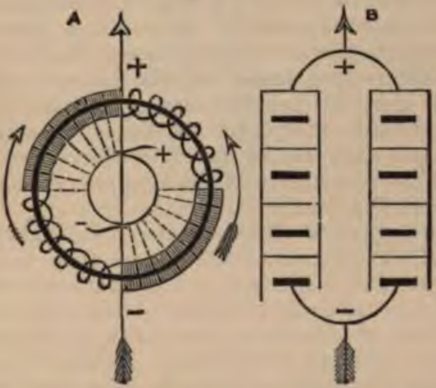
1061. *The Gramme machine* was the first practical machine with a *true ring armature*, § 845, the principal distinction of which is that it furnishes *a uniform and constant current in one direction*, while others give intermittent and alternating currents, which have to be arranged by the commutator. The reason is easily seen; in the earlier machines the wire in which the current is set up is constantly altering its position in the field, and is as *a whole* subjected to a growing and diminishing action in two opposite directions, hence the E M F set up is *of the nature of a succession of waves* alternately rising above and below the zero line, § 496: and the current resembles the stream set up by strokes of a pump. In the Gramme machine, although *each part* of the wire is constantly changing its relation to the acting magnetic field, *yet the wire, as a whole*, never changes its relation to, or position in the field; hence the inductive conditions set up are constant; the E M F set up is *of the nature of a constant fall of water*, and the current is a steady stream. To understand how this is arrived at, it is necessary to examine the apparatus and the conditions from several distinct points of view, § 1065.

1062. *The Gramme armature* differs from those of the Clarke type, Fig. 82, 3, in being a closed ring of metal, instead of an iron bar forming the core of an electro-magnet induced by the field poles; yet it is really just such a bar, if we consider its true functions: it will be seen in § 1066 that it is really two such bars dividing the field, and uniting their actions; the wire upon them being so arranged as to unite the currents developed. In order to effect this, the wire is not, as in ordinary electro-magnets a length of wire having two ends forming a constant circuit; it is a continuous and endless piece of wire wound over every part of the ring. Two distinct wires, each with its two ends, are really there as to action; but these ends, existing under the brushes, are not "objective," they travel along the physically endless wire.

Nor does the current flow through this circuit in its entirety, first one way and then the other, but two opposing currents flow in the opposing halves of the wire, or more strictly, no current flows in the wires, but equal opposing E M F's are set up, which unite in producing current if an external conductor is provided.

1063. The construction is explained by Fig. 95. The core is formed of hoop iron, or preferably wire, wound in a ring to

FIG. 95.



avoid Foucault currents. The conductor, of the size proportioned to the E M F and current to be obtained, is wound continuously over the core in one direction and its ends joined together; but though this wire is endless, there must be a constant connection with it at the points where it is cut by the vertical line + −. *Looking at the armature as a whole*, and as regards its relation to the magnetic field, the E M F's set up are shown by the arrows, which, it will be seen, represent the same conditions as a pair of equal batteries connected with their forces opposed, as regards themselves, but in multiple arc as regards an external circuit. In such an external circuit, therefore, they combine to set up a current; if no external circuit is provided, no current is generated.

1064. But the *different parts of the armature* are constantly changing their positions in the field, and therefore a temporary or shifting connection to the wire has to be made, as each of its turns crosses the vertical line: this is effected by the *commutator* composed of a contact plate for each *turn* of the conductor for large currents, or for each of a number of divisions of the conductor as shown by the dotted lines in Fig. 95, which represent the connecting wires; brushes pressing on the contact pieces make, practically, a constant connection with the two halves of the circuit on the vertical line. Thus we have really a stationary electric *circuit*, though the wire composing it is constantly changing, just as we have a fixed magnetic circuit or field, though the iron in which it is formed is changing, § 1025.

1065. If we conceive this armature inserted in the place of the Siemens armature in Fig. 94 we can trace its relations to the magnetic field, and note how a ring armature differs from the bar or horseshoe types. In these latter the armature, *as a whole*, reverses its relation to the magnetic field, and *assumes two distinct conditions at different times.* In the ring type, *the different parts* of the armature assume these conditions *successively*, and thus set up a rotation of the molecules of the wire as in other cases; but *as a whole, the two distinct conditions are assumed at the same time* in the two halves of the armature on each side of the vertical line in Fig. 102.

In the *rotation of a horseshoe armature*, the E M F set up in the wire, as a whole, varies with its distance from the magnet, producing the wave of currents § 1061. As the sections of the *ring* occupy all these several distances at once, the same varying E M F's are set up in them at once, as in the horseshoe wire at successive periods; but these sections being connected in series, they act as do a series of cells of different E M F's, and the resulting E M F in each side of the ring is constant, and is the sum of all those of the sections, as shown in Fig. 95.

1066. THEORY OF THE GRAMME RING.—These actions are shown in Fig. 96. N S are the field poles, not so far extended as is now usual in practice, and leaving out of consideration the distortio of the field explained, § 1056. If we consider the wire alon we see that it is (1) a helix traversing the field and cutting it lines *upwards* from 5 to 2, and downwards from 2 to 5, therefor producing opposite currents in the two halves of its rotatio (2) That the helix (disregarding the edges which lie parall with the lines of force), consists of two wires, on each sid cutting the lines, therefore there must be similar induction each, generating an opposing E M F in each turn of the wire, somewhat stronger in the outer position than in the inner, because of its greater nearness to the pole. (3) If we now insert the iron core, as in Fig. 97, it absorbs the lines of force into itself by its greater capacity, and these lines now exist *only in the spaces between the field poles and the ring itself*: the iron core becomes a shield to all the space within itself, and constitutes practically a magnet suspended between the two field poles. This results in two actions. (4) *The helix is now resolved into a single line of wires cutting the lines of force*, under the conditions of § 1051. No opposing E M F is set up in the inner portion of its wires, indeed they aid the action, because we may regard the system as a bar magnet, the core, traversing a helix, § 951. (5) But though the *magnet is fixed* in space, the iron in which it exists is being constantly changed; change of magnetic state means altered molecular arrangements, a consequent rotation of the molecules with the accompanying reaction upon its surroundings. This "polar introversion" is considered by Count Du Moncel to be the chief source of E M F in the Gramme. (6) This constant magnetic change in the iron has a disadvantageous result, because it heats the iron, and is doubly injurious, by the consequent waste of energy and by increasing the resistance of the wire by the heat thus given off, in addition to that due to the current in the wire.

Fig. 96.

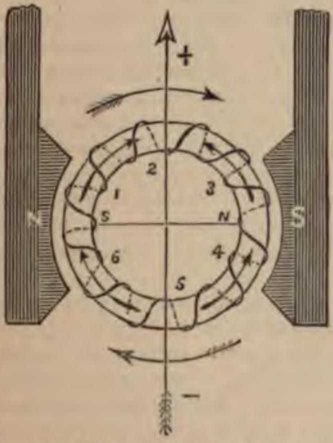
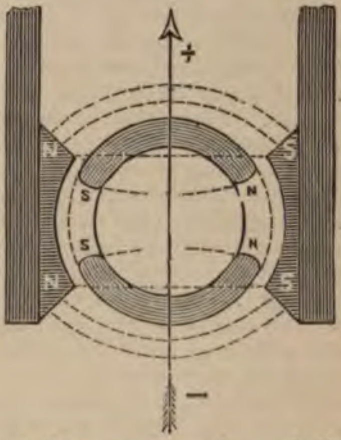


Fig. 97.



1067. The Siemens Drum Armature.—This acts on precisely the same principles, excepting the helix and magnet effect just referred to: though its construction is such as to bring them into action in a different manner. The core was at first a cylinder of iron, which may be regarded as a lengthened ring, of which Fig. 83, 3 may be regarded as a section, but this has been replaced by coiled wire and by discs of sheet iron, suitably spaced to allow air circulation.

The *wire* is wound along the length and across the ends of the cylinder, so that it represents only the single wire cutting the field on each side in opposite directions, in the air space between the field poles and the core; hence the wire crossing the ends is inert, serving only to connect the active longitudinal portions. The wire is divided into 8, 12, 16 parts, according to the size of the machine, all united, by means of the commutator segments, into one endless wire, as in the Gramme, but differently arranged. Many different modes of winding have been devised: in the original machines the wire crosses the cylinder diametrically at one end, but at the other passes from the middle of one polar arc to the extremity of the other arc.

1068. *The winding of the wire* is so arranged that the layer which is on each side facing the middle of the pole piece corresponds to one turn around the cylinder. Let us conceive an armature of 8 such turns, therefore of 16 wires, of which the *ascending* turns 1, 3–15 shall be regarded as related to the N pole, and on the left hand (as in Fig. 96), and the descending turns 2, 4–16 as related to the S pole on the right. Let us begin with 1 at the middle of the N pole, and connected on the further end of the cylinder to the lower end of 16 which faces the middle of the S pole. The commutator consists of 8 strips which we may call *a*, *b*, – *h*, of which *a* lies nearest to wire 1: this upper end of wire 1 is now led across the end of the cylinder to the upper end of the S field pole, where it descends as wire 2: the winding has thus advanced one-eighth of th circumference, *against the hands of the watch*; the cross wire is al connected to armature segment *a*: that is to say, the *end of w* 1, and *beginning of wire* 2, are joined together at *a*. Wire 2 th commencing at *a* and crossing the lower end to the point o eighth further advanced—that is, to opposite the lower point pole N, we may consider as wound round and round the cylin between 2 and 3, so as to fill up one-eighth of the cylinder: turns in the space corresponding to 2 and 3 therefore constit one helix crossing the cylinder, and constituting the next lection of wires which will come into the highest action as cylinder rotates in the direction of the hands of a watch. end of 3 and the beginning of 4 are in like manner connected segment *b* of the commutator, that is to say, to the next one to *a*, working round the commutator, as the wire itself does against the hands of the watch.

1069. *The neutral points* are, as in the Gramme, on the vertical section of the field, and the currents set up in the various sections of the ring are just like those in the Gramme as shown § 1062 and Fig. 95. But little E M F is generated in the sections 4–5, 6–7, which occupy the middle of the field and whose ends are connected to the commutator segments near the neutral line: they only conduct the current to the neutral points. Therefore the commutator brushes *overlap at least two segments*, thereby short circuiting these idle portions of the wire, or cutting them out of action so as to reduce the resistance. A similar object is attained in like manner in the Gramme, and so long as the brushes occupy the neutral axis the only sparks produced will be due to the vibration and jumping away of part of the brushes. If any considerable sparking occurs it proves that the brushes do not occupy the true neutral points due to the actions explained, § 1037. The Siemens field system is shown Fig. 92, § 1054.

1070. The Siemens *drum* is a link of evolution between the *bar* armature of Fig. 94, and the Pacinotti *ring*. It is *not derived from the Gramme* machine, or a mere modification of the Gramme ring as it is commonly said to be. It is likely enough that it was suggested by the consideration of the Gramme action; but it is truly the Siemens core of Fig. 98. This is more evident with the solid core than with the cylinder, because each section of the wire with its internal iron corresponds to one H core.

1071. The Gramme ring and Siemens drum practically include all the various forms of machine in use for continuous current generation, the various forms of machine representing, not principles, but details of construction. The Clarke type includes several useful machines used in electro-metallurgy, such as the Weston and several similar ones, whose current is not really continuous, but composed of successive impulses, of one direction, but of an undulating E M F which appears to work with some metals even better than the true continuous current. As space will not permit description of the special forms, these typical ones, which present the principles of all, can alone be dealt with.

1072. ALTERNATING CURRENT MACHINES.—These are now coming into use in the large electric light installations, particularly the *Gordon* and the *Ferranti-Thomson* machines. They are simpler in construction than direct current generators, and more suitable for giving a very high E M F; this is indeed the motive for their use, as the higher the E M F, the less the cost of transmission, § 569. But it is still an unsettled question whether on the whole the advantage lies with the high E M F alternating current combined with transformers to bring it within safe limits, or the lower E M F continuous current aided by secondary batteries. The continuous current has the advantage that it can be stored, and is useful for every purpose as well as lighting. The alternating current is useful for lights of the "candle" type, and is, more doubtfully, said to be better for incandescent lamps, so far as duration is concerned: but it is useless for electrolysis, and whether it can be used mechanically remains to be seen, § 1113.

1073. The description of these machines to be of any service, would occupy more space than can be spared, and would be of interest only to those who can readily obtain the same of a more complete character than would be suitable here. The same remark applies to the so-called "multiple phase machines" producing a rotating magnetic field, quite recently applied successfully to transmitting power over considerable distances during the Frankfort Exhibition, and in regard to which, and motors for use with them, M. Tesla is doing good work. But even if perfected they will be of so complicated a character that they will remain in the hands of skilled engineers. It will be more useful to consider matters of more general interest in the construction and use of machines available generally, § 1117.

1074. Field Magnets.—For the sake of *economy*, they should be constructed as to size and wire, so that they shall nearly reach the limit of saturation at the fullest limit of work.

For *steady working under varying conditions*, they should be well within the limit of saturation.

For *automatic adjustment*, they should not approach that limit even at full work; they should still be in conditions which increase magnetism proportionally to current, § 971.

The *length* for a given weight is governed by the same law as those for electro-magnets, § 991, in fact they must be regard as electro-magnets intended to produce a very concentrated fi

The *pole-pieces* should contain one-quarter of the iron of magnet, and the arms should be rather of one mass than divi into several, and should therefore be of a thin and broad secti so as to be fully influenced by the coils, rather than circular.

The winding of the wires is arranged on different systems to special requirements.

1075. *Separately excited* machines are independent of variations of the work doing. They are those with perma field magnets, or those excited by a separate machine, whic necessary when the machine itself is one for alterna currents, though the two machines are in some cases driven upon one axis, §§ 1020 and 1023.

1076. *Self-exciting machines*, in which the principle of accumulation, § 1021, is fully utilized, are of several different orders of field magnets. They are made as series and shunt machines, and as different combinations of these. Fig. 98 shows the field-magnet separately excited, Fig. 99 the series circuit, and Fig. 100 the shunt system.

1077. *Series* machines, Fig. 99, are those in which the whole current passes through the wires of armature and field, and the outer circuit, all being in series. The result is that as the outer resistance diminishes, the intensity of the field grows, and current increases. This fits them for the variable work of electro-metallurgy.

Fig. 98.

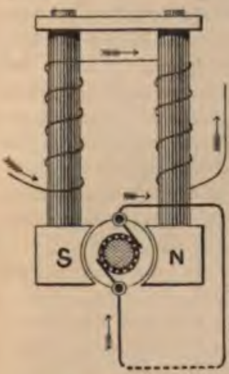


Fig. 99.

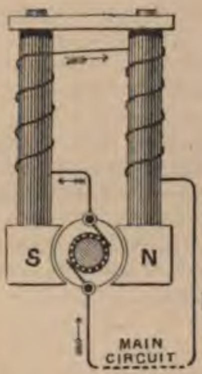
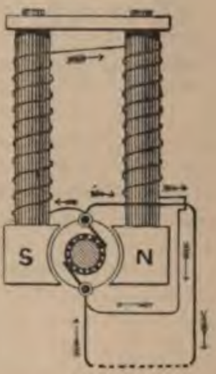


Fig. 100.

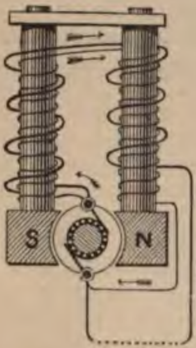


On the other hand they are difficult to start against a large resistance, and may need a temporary shunt to get current enough to magnetize the field magnets. They are also liable to be reversed by a counter current. Several means have been used to overcome these objections: Weston used a rotating governor in a mercury cup, which only closed the circuit when a fixed velocity was attained. Gramme used a circuit closer actuated by the field magnet, which kept the outer circuit open until the field magnet was charged.

1078. *Shunt* machines, Fig. 100, divide the armature current between the field magnets and the outer circuit: with open circuit only enough current is generated to just charge the field magnets. When work is doing, the total resistance being lowered, more current is generated, part of which goes to the field circuit, increasing the magnetic intensity. But this regulation, while automatic, is very imperfect.

1079. *Shunt and Series* machines combine the two systems, as shown in Fig. 101; one wire, the shunt, is as just described; the second, the circuit wire, instead of going to the + terminal direct, is first taken round the field magnets, as well as the other and then to the + terminal, so that at all times the *whole of the armature current* traverses the field magnets; but the proportion of it in the two wires, and the total current produced, depend upon the external resistance. This gives a very complete adjustment of current to varying conditions of external resistance.

FIG. 101.



1080. This arrangement has been employed in various machines, at first purely to overcome the difficulties mentioned, § 1077. Thus Brush wound a fine wire circuit of great resistance over the core, calling it a *teazer*, to secure some magnetism of a definite direction in the field as soon as the machine moved. Weston did the same. Some years afterwards Messrs. Crompton and Kapp discovered that by giving a definite resistance to the field circuit and putting it outside the working or series circuit, the dynamo became self-regulating. One extract from their patent specification will best explain the principal of "compound winding."

> "One method of carrying out this compound winding is to take a machi
> having an armature resistance of say 0·1 ohm and wind on its field magnets, next
> to the core, sufficient No. 5 B.W.G. wire to give a resistance equal to that of the
> armature, and couple the same in series circuit with the armature. [This is the
> series circuit in which the external work is included, § 1077.] Outside the
> coils we wind on sufficient ·057 inch wire to give a resistance of from 2
> 30 ohms; we couple this from brush to brush [this is the shunt circuit § 10
> Such an armature we prefer to drive at such speed that the EMF, when
> R of the outer circuit is infinite (that is, open) will be about 65 volts. It
> be found that if the external circuit be now closed through resistances vary
> from infinity down to 0·75 ohm, so that the current varies from 2 ampères, u
> 80 ampères, the electromotive force between terminals will remain nearly
> stant at 65 volts. Moreover that the magnet charge or extra current of
> short length of low resistance coils will be so small, that 40 or 50 lamps ma
> switched simultaneously out of the main circuit, without producing any mo
> tarily hurtful increase of current in one lamp left in circuit."

One of those curious legal decisions of which the elec patents have been the subject of late years gave to Brush the patent right to compound winding.

1081. THE E M F OF DYNAMOS.—The first essential for success in electric lighting is absolute steadiness. (1) There must be no fluctuation in the light itself: this means uniform E M F, and necessitates perfect steadiness of motion in the driving engine, to attain which the engine ought to have a large margin of power so as not to be near its limit of work; it should have a heavy fly-wheel, and a fly-wheel should be attached to the axis of the dynamo itself. (2) The available current should not be either increased or reduced by the sudden turning on or off of other lights; this means that there should be maintained a constant E M F at the terminals of each lamp. (3) In electro-metallurgy each kind of deposit requires a definite E M F, no matter what the quantity of work doing, and it needs a current which will increase as the work is increased. This is the same requirement as that of (2). For such cases a machine giving constant E M F is needed: that is, a properly compounded series shunt machine.

On the other hand, when a number of similar operations have to be effected in *series*, constant current is required with a variable E M F.

1082. *Constant E M F at the terminals of the work*, § 1086, is the desideratum, not constant E M F generated by the machine in the armature ring. Now E M F is changed by

(1) Variation of speed.
(2) Varying the strength of the field.
(3) Altering the number of turns of wire in the armature.

The second is the practicable mode. It may be effected in magneto machines by arranging an iron armature to slide over the arms along the length, or made to either move across the field, or to approach or recede: medical machines are fitted with a movable armature for this purpose.

1083. *Magnetic force varies* in electro-magnets in two ratios: (1) as the number of turns of wire: (2) as the current passing: or, § 994, *in a given magnetic system the force varies as the ampère-turns.* The number of turns cannot be conveniently altered, but the several field magnets do control the ampères.

In *separately excited* machines, this is effected by altering the current from the exciting machine, while in *self-exciting* machines the actions described, §§ 1074–80, control the field intensity.

1084. QUALITY OF IRON.—*Armature cores* should be made of the softest wrought iron, though good malleable castings are employed in some cases: the greater the rapidity of the changes which occur, the more essential this is, as any tendency to residual magnetism will lower the efficiency. For *field magnets* different conditions exist: in them *residual magnetism is essential*, so that ordinary cast iron may be used. On the other hand E M F depends upon the "magnetic intensity" and this upon the *capacity* of the iron, § 969. This varies greatly in different irons, being greatest in the purest and softest wrought iron. Both theoretical considerations and experimental results indicate that the highest effect will be obtained from soft iron cores to take up magnetism from the current, good malleable castings for the pole-pieces, and massive connecting pieces of hard cast iron to serve as reservoirs of magnetism: in some cases steel plates have been combined with soft iron for this purpose of maintaining residuary magnetism when the machine is not running.

1085. RATIOS OF RESISTANCES.—The relative proportions of external resistance to that of the field magnets and armatures have been greatly varied as the subject has been studied. According to the formulæ of Sir W. Thomson, in the British Association Report 1881, the resistance of the field magnets should be a little less than that of the armature in the case of series dynamos. For shunt machines the formula is

$$R = \sqrt{F \times A} \text{ and } F = R^2 \div A$$

R is the resistance of the external circuit.
F " " field magnets or shunt.
A " " armature.

1086. *Relations of Internal and External Resistance.*—As in batteries, there is a law connecting these to useful work. Economy means that the greater part of the resistance should be external, and that it should be of the nature of *work*, § 525. The laws of distribution of potential, § 491, show that only the E M F which is expended in this "work resistance" is of use; the rest is expended in driving the energy to the point of application. Therefore we have to consider four distinct divisions of the E M F set up in the dynamo, each of which, multiplied by its own current, gives the relative energies.

(1) The E M F at the terminals of the working apparatus, say the electrodes of a plating vat, or the connections to lamps: this is *the energy utilized.*

(2) The E M F at the terminals of the dynamo, which includes the first, and also that expended in the conductors. The difference of 2 − 1 is the *expenditure in transmission.*

(3) The E M F in the field magnets, expended in maintaining the force of the field.

(4) The E M F at the brushes, that generated by the armature,

of which the others are portions. The energy expended in the armature itself is given by $C^2 \times R$.

1087. The *efficiency* of a dynamo machine is often reckoned from its capacity as a converter of mechanical energy into electrical, by the formula $C^2 \times R$. But the electric energy expended *within the machine* is as much waste as the mechanical friction.

The *true efficiency* is represented by the ratio of the *energy in the external* circuit, to the mechanical energy expended in driving; this is what interests the buyer of a dynamo. It may be of much interest to the theorist (or the seller) to prove that electricity converts energy with little or no loss; that a dynamo gives us in *electrical horse-power*, § 427, 90 or more per cent. of the *mechanical horse-power* supplied, the remaining 10 per cent. being the inevitable loss in friction. But the real question for the user of the machine is, *how much of this* 90 *per cent. turns up in useful work?* that is shown § 1086.

1088. *Very high efficiency* may be too dearly purchased; the last 5 or 10 per cent. costs more by a great deal than any other. It means much better quality of material, finer work, more liability to getting out of order, and more expensive repairs. For most practical purposes "excelsior" lands us in fogs and danger as it did Longfellow's much over-appreciated Alpine tourist: the humbler aim of quiet steady duty, work done, is much better. The machine to be sought after is one which with fairly good efficiency, say 80 per cent., sends a good share of it into its productive work, will not require too much skilled attention, but will endure the ordinary conditions of practical operations. Moderate speed is preferable because great speed means wear and tear; relative heat developed is an important consideration, as high efficiency generally means pushing the current density in the wires to the limit of safety, with liability to breaking the insulation down. Finally there is the question of cost; the interest and depreciation + the cost of working, spread over the quantity of work to be done.

1089. ELECTRO-MAGNETIC ENGINES.—Not many years ago it was settled that electric motors were out of the field of practical science; that was because zinc is too costly a fuel: now it appears likely that their manufacture will be, at no distant date, the most important branch of electrical engineering. Trustworthy motors are now to be had giving an efficiency of 70 to 90 per cent. For traction purposes they are being closely studied. For factories it would seem that they may advantageously replace the shafting and belting for transmission of power, each machine having its separate motors. But their great use will be when electric current is distributed at a cheap rate: already the American companies find it to their advantage to distribute power at a less charge than light by the same circuits, because the call for power employs their plant just when it would be idle: many domestic uses will arise for a simple and cheap power machine to save labour.

1090. From this aspect the considerations of § 1071 will be important, as those companies who supply alternating currents will be at a disadvantage: on the other hand this very fact will stimulate the endeavour to perfect motors worked by alternating currents.

1091. *Early Forms.*—The earliest and simplest electro-motor is the rotating mercury break which was used for induction coils. Between the arms of a horseshoe permanent magnet is a wooden block on the face of which is a circular groove, divided into two parts, which are the connections to the circuit, by plates of ivory. In the centre a tube serves as bearing to a steel pin carrying a bar electro-magnet which rotates between the poles of the horseshoe: the ends of its wires descend so as to just clear the ivory slips, and dip into mercury, contained in the groove, which rises above the level of the divisions: therefore, the magnet reverses its polarity as it passes the pole, is then repelled till the attraction of the other pole comes into play (or more truly the bar travels along the lines of the electric field between the poles), and so a continuous rotation is produced. We have here, not only the stages by which motors have been generated, but the very principles on which they depend.

1092. Then we have an iron armature on a lever playing between two electro-magnets, alternately excited, or an electro-magnet similarly placed and alternately reversed, and this oscillating motion transformed into rotary motion, as in the steam engine, by a crank operated by a prolongation of the lever. This is still used for such purposes as rotating vacuum tubes with induction coils, and other cases where motion is needed with little work.

Another system was based upon an iron bar attached to the lever, but plunging into a coil; Hjorth's electro-magnet, made as a hollow cone, gave the best effects because it equalized the pull over a considerable range.

1093. *Modern types of motors* correspond to those of dynamos; in fact any dynamo can be reversed into a motor, and any motor will generate current; but though they are thus reciprocally convertible, it does not follow that the best generator will be the best motor: on the contrary, there are functional differences which require to be met in different ways, and particularly in the proportioning of the parts, and the relation of the field and armature systems; in the dynamo, the magnetism of the armature is a result of the field, but in the motor it has its own independent existence: as a consequence, in accordance with Lenz's law, § 950, the magnetism of the armature opposes that of the field, resulting in distortion, § 1056, and weakening of the field in the dynamo, while in the motor the two poles reinforce, though still mutually displacing each other.

As a consequence, it is desirable to make the armature magnetism weak in dynamos and strong in motors. The *lead*, that is the displacement of the neutral point, and consequent position of the brushes, is also different.

Motors should have the moving parts light, so that they may rotate rapidly, which is a prime condition of efficiency, and there being less momentum, they start and stop easily. But where a steady action is required, they may have more weight, so as to serve as their own fly-wheel.

1094. Motors, like dynamos, and in fact, all engines, are of two types, distinguished by the production of alternating and continuous currents in the armature. This does not relate to the real alternate current motors, which change in both field and armature, or use an alternating current supply, but to an internal reversal of the current by the armature itself, § 1009. It divides constant current motors into the same types as the dynamo, the *Clarke type*, § 1017, and the *ring or drum* type, § 1037.

1095. *Clarke type* motors are based upon Siemens' core, and are small Siemens machines, as stated § 1059.

(1) *Deprez* has a remarkable divergence from the ordinary plans, in that he places the armature not in the interpolar space where a concentrated field is produced, but *lengthwise between the arms of the magnet*, which is a permanent one. It is true that the magnetic lines do cross the space between the arms to some extent, *as leakage*, § 976: it is also true that the presence of the armature would draw the lines into this space, and prevent the extension of the magnetic force towards the poles: but this would tend to a strong molecular disturbance in the magnet at each semi-rotation of the armature, and it would seem better to use the normal field formed at the ends.

(2) *Trouvé's* motor is simply a Siemens machine with electro field magnet, and the armature ends elliptic instead of circular.

(3) *Griscom's*, which is made so small as 2 lbs. in weight, is the same as Trouvé's but the field magnet incloses the armature.

Many others make and name machines of this type, but though they may have their uses, their efficiency is so low that they are very wasteful, and they are only made in very small sizes.

1096. *Continuous current motors* are derived from any of the dynamo machines, and Messrs. Ayrton and Perry made them inverted, that is with the armature fixed, and the field magnet rotating. There are now many patented forms and many makers, each of whom no doubt produces the best machine; at any rate, a good machine can be obtained from many makers by those who master the general principles and know what they want. It would be invidious to select any for special description, as space would permit no useful description of the special forms.

1097. Points of importance in selection are, as with dynamos, § 1088, first cost, efficiency, weight, and space occupied in some cases, and especially the avoidance of dead points which make starting difficult: as a rule also, quick running is an advantage here, with gearing or countershaft to adjust this to the speed required.

1098. When two dynamo machines A, B, are placed in circuit together, with a galvanometer to measure action, when A is rotated it generates a current which passes into B; if this is prevented from moving, the galvanometer will show a current due to the E M F corresponding to the speed of A, while B plays the part of a simple resistance.

If B is also rotated, and the connections are such as to oppose the two machines, we may have no current at all, and the machines will require no more power to drive them than corresponds to the mechanical friction.

If B is left free it will rotate itself as a motor, and the galvanometer will show a current less than that produced when B was not in motion: the reason is that the motion of B, however produced, generates an E M F which, when produced by the current, is an opposing E M F, corresponding to the counter E M F set up in a voltameter.

1099. *The efficiency of motors* may be ascertained by the E M F they generate. Thus current being passed while the machine is at rest and its value noted, the efficiency will be related to the reduction of current when the machine is allowed to run free, doing no work, for if the machine were perfect it would generate a velocity closely approaching that which would generate an E M F equal to that producing the current: this being of course impossible, any current actually passing measures that expended by the machine in internal work.

Subject to remarks, § 1097, the test of value of a motor is its *efficiency*, that is its return expressed as

$$\frac{\text{Energy produced}}{\text{Energy supplied}} = \text{Efficiency.} \qquad \frac{\text{H.P.}}{C \times E \times J} = \left\{\begin{matrix}\text{percentage} \\ \text{returned.}\end{matrix}\right.$$

The energy supplied being measured by the current used in driving, partly lost in heat in the wire and iron, partly in mechanical friction; the energy produced being measured by the weight lifted, or by a dynamometer.

The next consideration is the relation between efficiency and the cost or convenience of the machine, as related to its size or weight. It follows that the *efficiency* of motors with steel permanent field magnets should be higher than those with electro-magnets, but that as to the second consideration the electro-magnet has the advantage.

Small motors do not give nearly the same efficiency as large ones, but that is the case in most operations.

1100. *The direction of rotation* depends on the position of the armature poles as compared with those of the field. Therefore a dynamo machine used as a motor would not reverse its direction upon reversal of the current, because both sets of poles would be reversed: reversed motion is produced by the reversal of the current in the armature or field alone; usually the armature, which is intended to undergo changes of magnetism.

The *position of the commutator* contacts in motors is different from that of generators, being either on the central line, or with a backward "lead," because the pole, being generated by current delivered at the contact, attains its maximum a little in advance of this point, § 1056.

1101. Motors should always be worked on the *multiple arc* system, so that there should be no mutual interference, but all being supplied and adapted to a constant E M F, each will close its own circuit, and call forth the required current from the generator, as described § 1082.

1102. Cost of Working.—The utility of a machine, and the possibility of its employment (where conditions of convenience do not override all others), depends upon *the cost of a unit of energy* delivered by it, and this is based upon (1) the cost of the source of energy; (2) the efficiency of the conversion.

1103. Cost of Energy.—This has many expressions to suit different purposes. For mechanical energy the *horse-power hour* is the most useful, until mechanical engineers are willing to adopt Mr. Preece's suggestion to make the horse-power correspond to 1000 watts instead of 746, § 427, which would make it equivalent to the B.O.T. unit which corresponds to 1000 watt-hours. The *equivolt*, § 597, or some multiple of it has many advantages for chemical purposes: but we have now to deal with mechanics, electricity, and money value, and the special unit of the supply companies is the proper one to use. Let us define its relations to other units.

1104. A *horse-power*, H.P. is 33,000 foot-lbs. per minute.

A *horse-power hour* = 33,000 × 60 = 1,980,000 foot-lbs.

A *man's power* is usually taken at one-sixth of horse-power.

The *B.O.T. unit* is, § 428, the energy of 1000 volt-ampere hours, which is 3,600,000 joules, and the joule, § 426, being foot-lbs. ·7373, we have these data, with the logarithms for calculations.

H.P. hour = 1,980,000 foot-lbs. 6·2966652.
Joule = ·7373 " −1·8676442.
H.P. hour = 2,685,474 joules 6·4290210.
B.O.T. unit = 3,600,000 " 6·5563025.
" = 2,654,300 foot-lbs. 6·4239467.
" = 1·34 H.P. hours 0·1272815.
" = 568 equivolts 2·7543509.

The price charged by supply companies ranges between 5*d.* and 10*d.* in London per unit: we may take 6*d.* as a value easily altered in calculations.

1105. Energy of Fuel.—This is usually valued in terms of units of heat, generally that amount of heat which will raise 1 lb. of water 1° Fahr. in temperature, which is equivalent to 772 foot-lbs., § 582. According to Favre and Silbermann, the value of carbon per lb. is 12,906 units, and of hydrogen 62,535. According to the Government experiments on coal, the average of English qualities may be taken as—

Carbon, per lb. .. .. ·812 × 12906 = 10480
Hydrogen (available), per lb. ·041 × 62535 = 2564
10,070,000 = foot-lbs. per lb. = 13044

This is 3·7939 B.O.T. units or 5·075 H.P. hours.

1106. We must next consider the proportion of this actually utilized in steam engines. This will depend upon their consumption per "indicated horse-power," and this varies from 2½ lbs. per hour in the best engines to 5 and 6 in common ones.*

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* The indicated horse-power is usually employed as the measure of work and merit of an engine, but it is not really so, as it does not allow for the friction of the engine itself. The correct value can be ascertained only by some kind of dynamometer which measures the actual mechanical energy exerted at the driving pulley of the engine per indicated horse-power developed in the cylinder, as this latter measures the proportion of energy of the fuel transformed into pressure on the piston by the agency of the boiler and cylinder.

Let us take 4 lbs. as the consumption of a fairly good engine: let us take 20*s.* per ton as the price of coal as a convenient figure to correct to actual prices: this gives us ·10714 of a penny as the cost per lb., which, if we like to make 1*s.* per ton the basis to be multiplied as required, becomes ·005357. The cost of the horse-power hour at 20*s.* is therefore, at 2·5 lbs. per hour, ·26786, and at 4 lbs., ·42857 of a penny. It appears that the London supply companies average 7 lbs. of coal per unit, or 5·22 per horse-power hour, owing no doubt to the demand not being constant.

1107. GAS AS FUEL.—A ton of average coal gives 9600 cubic feet of gas of ·450 sp. gr., which is 331 lbs. of gas per ton; about 1300 lbs. of coke are also produced, and if we allow even one-third of this as consumed in the furnaces we may consider we get about 12 feet of gas for each pound of coal consumed, that is, 100 feet represent at most 8 lbs. coal. The energy of gas is, weight for weight, much greater than that of coal, for the reasons given § 586: in fact, the energy of large part of the coke consumed really passes into the gas, in the act of gasification of the solid coal: according to various tests 1 lb. of gas gives 22,000 heat units, or 17,006,000 ft. lbs., and as there are about 30 lbs. in 1000 feet this means 510,000,000 ft. lbs. per 1000 feet, or theoretical H.P. hours 258.

1108. But we can easily take pretty certain figures here; we can fairly take the prices of gas as 3*s.* per 1000 feet, and there are gas engines which work at 21 feet per H.P. hour, or practically 49 per 1000 feet. This works out to ·1398 of a penny for potential energy of gas, and ·7560 for the practical H.P. hour *including labour*, because the gas engine needs no stoking, against the coal cost, § 1106.

1109. Petroleum oil evaporates 15 to 18 lbs. of water per lb. against 10 to 12 for coal: it costs much about the same as gas, at all events for light, and probably for engine power.

1110. *Cost of Electric Energy.*—Taking the price per unit at 6*d.*, the cost of H.P. hour is 4·4758 which, divided by the efficiency of the motor, gives the practical cost per H.P. hour in pence.

I have tabulated these various costs for comparison, adding the cost by batteries, taking the cost, table, p. 153, with ·015 per 1000 joules as average: this cost, like that of steam engines, would be increased by the waste and the cost of labour, which is not incurred either by the gas or supply-fed electric motors.

1111. *Cost of Local Working.*—If we take the case of home manufactured current at 4 lb. of coal + an equal sum for labour, it is clear that the cost will be this sum increased by the efficiencies of dynamo and motor. Taking these at 80 per cent.

we have cost of electric energy per H.P. hour 1·0714, and mechanical energy 1·3392 pence. These figures do not include cost of machinery, wear and tear, &c., which have to be added in this case for engine and dynamo as well as for the motor, which is alone needed with supply current; nor is any allowance made for conductors, leakage, &c., such matters depending on local considerations.

The cost of lighting the Athenæum Club locally is 894*l*., and it is said that the cost at 7*d*. would be 1452*l*.: this means 49,782 units, produced at a cost per unit of 4·3*d*. or per electrical H.P. hour 3·216, which at 80 per cent. efficiency, to compare with other figures, means 2·576 pence as the actual cost per mechanical H.P. hour.

Cost of Mechanical Energy per H.P. Hour.

§		Data.	Practical.	Logarithm.
	FUEL *Theoretical.*			
1105	*Coal*, work of 1 lb. = 3·7939	..	..	0·5790814
1106	„ cost in pence 1 lb. at 1*s*. per ton	·00536	..	−3·7289332
„	„ „ „ 20*s*. „	..	·10714	−1·0299632
	Working steam engines—			
„	at 2·5 lbs. per H.P. hour	..	·26786	−1·4279032
„	4 „ „ „	..	·42857	−1·6320232
„	„ with labour	..	·85715	−1·9330532
1107	*Gas* at 3*s*. per 1000 c. ft.	·13976	..	−1·1453975
1108	„ engine at 21 feet per H.P. hour	..	·75600	−1·8785218
	Electric motors—			
1110	worked by batteries	40·282	..	1·6051123
„	supply at 6*d*. B.O.T.	4·4758	..	0·6508698
„	*efficiency* 50 per cent.	..	8·9516	0·9518998
„	„ 70 „	..	6·3940	0·8057718
„	„ 80 „	..	5·5947	0·7477798
	Home generated current—			
1111	Electrical H.P. at 80 per cent. ..	..	1·0714	0·0299632
	„ motor „ „ ..	..	1·3393	0·1268732

1112. TRANSMISSION OF ENERGY.—This subject, as to which great expectations have been put forth, naturally comes to be considered here. It will be seen that the practicability of transmission to considerable distances depends upon the proportion of energy delivered to that generated, that is to the waste of energy in the acts of transmission and conversion, and as to this, there are two considerations: (1) the effects with *large currents*; (2) the results with *high E M F.*

The principle object is to utilize the natural energy of waterfalls; that of flowing water can be utilized best in its neighbourhood: many have tried to utilize the tidal energy, but that, it is well proved now, cannot be done profitably. Another source of energy might be found in waste fuel at the mines which is not worth carriage, and except where it is made into compressed fuel, goes to waste. I may suggest that a source of cheap energy might be found in burning this fuel at the bottom of upcast shafts of mines: this has long been done for ventilation purposes, and it would be easy to add apparatus to generate electric current: possibly even the thermo-pile on a large scale might be utilized in this, and other cases, where heat is going to waste, as in flues.

1113. *Transmission by large currents* is now recognized as impracticable over any serious distance, because of the cost of the conductor and loss of energy in it.

Transmission by high pressure with continuous currents is limited by the difficulty of producing dynamos to furnish over 2–3000 volts. As the object is to attain the highest voltage which can be kept within the conductor, *alternating currents* give the best prospects.

1114. The problem is complex, and its separate parts will probably receive different treatment. It seems probable that the alternator will have to take the mechanical energy from the water wheel or turbine and transmit it, possibly at 20,000 or higher voltage, over aerial conductors to the point of consumption, where transformers will reduce it to a manageable voltage for local distribution.

1115. Whether it will be distributed in the alternating form depends upon whether alternating motors become trustworthy: may it not be that the true process will be to employ at the receiving station an alternating motor (manageable there) driving a generator producing continuous current? Local substation transformers are coming into favour for light distribution, and similarly, we may have motor generators transforming the high voltage alternating current into a low voltage continuous one, suited both to motors of simple construction, and to chemical uses, as well as light giving.

1116. The latest experiment, at the Frankfort Exhibition 1891, appears to have been successful: full particulars are not yet published, but just as this part has to go to the printers, a preliminary account has appeared.

A *voltage* of 16,000 volts was used but raised occasionally as high as 30,000. Insulation by the oil insulators, as introduced by Messrs. Johnson and Phillips, was found to be quite trustworthy, only one insulator giving way under the stress itself: there was no leakage.

2 1

The *capital outlay* was £60 per H.P. transmitted, of which £50 was devoted to the conductor.

An *efficiency of transmission* of 72 to 75 per cent. is calculated to have been attained, but further definite evidence is desirable.

The distance from the waterfall at Lauffen to Frankfort is 112 miles, and the calculations were at first based on a current of 8 amperes at 27,600 volts in a copper conductor of ·06 sq. in., with a fall of potential of 10 per cent. Transformers with oil insulation were used, and the generating apparatus was the "Dehstrom," the rotary field dynamo of M. Dobrowolsky. I give description of this, condensed from a paper by Dr. Oscar May.

1117. The current is a combination of three alternating currents, with their phases following each other, giving a displacement of 120°, thus producing a rotary magnetic field. The three classes of currents, "continuous," "alternating," and "rotating," may be illustrated by the action of a magnetic needle surrounded by the conducting circuit.

With a *continuous* current the needle assumes a fixed position, its deflection; with an *alternating* current (of low frequency) it swings from side to side; with a *rotary* current (in three separate wires) it rotates on its axis. If the needle is replaced by an iron cylinder, a rotating motor is obtained which has neither winding, collector, nor contact ring, and of which the armature is not included in the circuit; such motors will start with a load, as they have no "dead points" as alternating current motors have.

1118. The action depends on the same principles as those utilized in Shallenberger's meter, § 400, as the successive currents induce poles in the iron armature and currents in closed wire circuits on it; the induced poles of the armature always travelling round and following those of the revolving field of the current set up by the different circuits.

Therefore as there are three circuits in the machine, three conductors are necessary, but the interchange of actions enables each of these in turn to serve as return wire to the active circuits of the moment.

1119. Some years ago Messrs. Thomson and Houston claimed that the total power of Niagara could be transmitted 500 miles by a half-inch copper wire. That has not been done, but steps are being taken to utilize some of it, and Professor Forbes states that he has recommended Mordey's alternator for the purpose, working at 10,000 volts.

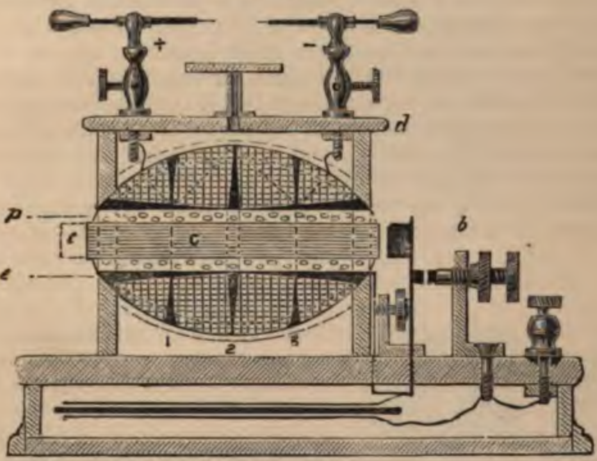
1120. It should be understood, when calculating the energy of a waterfall, that its "total" power can never be taken up by any mechanism: the water issuing from the turbine, or wheel, must retain *some* velocity, or the machine would stop altogether, and the energy absorbed from the water will be as the difference of the squares of the velocities of flow above and below the turbine. This only gives the energy *collected*, and is subject to losses in distribution and mechanism.

The turbine is one of our most efficient machines, and may be estimated to deliver 75 per cent. of the power due to the "head of water."

1121. Induction Coils.—These are an application of the principles studied, §§ 938–953. They consist of distinct parts, the function of which should be understood. (1) The iron core. (2) The primary wire which conveys current from the battery. (3) The break which interrupts the current. (4) The secondary wire in which the induced current is set up. (5) The insulation. (6) The condenser.

Between all these parts there is a due proportion, and Fig. 102 is drawn to a scale intended to exhibit that proportionate relation for the best construction: it represents a coil with a core 1 foot long and $1\frac{1}{8}$ inch diameter. The proportions are related to the laws of electro-magnets, modified by the circumstance that the core cannot be saturated, and is only acted on for a fraction of a second: therefore it should not be so long as a real magnet; on the other hand, for very large coils, the length

Fig. 102.



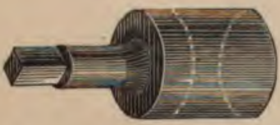
is advantageously increased so as to reduce the distance of the secondary. The ellipse shows the most advantageous form in which the wires can be arranged to occupy the most effective portion of the space marked in thick lines from the points *a b*, in Fig. 77, § 953, and the following explanation will assist in the making of a coil to the best advantage.

1122. *The Core.*—This acts purely as an electro-magnet, and should be made of the purest and softest iron, so that it may magnetize and demagnetize rapidly and completely. It must not set up an induced current within itself, therefore its own metal must not form a circuit which would act as does the brass covering tube described, § 1148. It should be made of wire, 18 to 22 gauge, cut in lengths in excess of the intended coil, so as to project at both ends, as shown in dotted lines at one end *c*: they should be packed into a metal cylinder of proper size, from which they can be gradually pushed out and bound with iron wire: they should then be placed in a charcoal fire, made red hot for some time, and allowed to cool as the fire goes out—not by removal. The binding wire should be gradually unwound, and replaced by tape covered by strips of stout paper pasted on to form a cylinder, which, when dry, should be warmed and soaked in melted paraffin.

When a removable core is desired for experimental purposes, or such an arrangement as is described, § 1155, for medical coils, it is better to form a cylinder of paper, or ebonite, &c., on a slightly tapering mandril, and construct the coil upon this, inserting the core afterwards.

1123. Fig. 103 represents a cap of metal to be fitted on to each end of the core or to the mandril, to work in a slot in an upright frame so that a handle can be slipped on either end to wind up the coils of wire. This could be done in a lathe, but is far better done by hand in a frame for the purpose.

FIG. 103.



When the coil is completed, the caps (which may be secured by shellac cement) are removed, the end of the core at *b* is to be cut off and filed to a perfectly smooth face: the end *c* projecting beyond the calculated length of the core, and the armature at the other end will both add to the inductive actions, as in § 981, by the increased magnetic capacity.

1124. *The Primary.*—This should be silk-covered, because the magnetism induced depends upon the current and the *number* of turns of wire, and this will be greater, the less room the insulation takes up; it should be of high conductivity, and soft, so as to have no spring in it. The size must be selected with an eye to the battery power intended to be used, so as to develop the greatest current. No. 14 would suit a coil a foot long to work with low battery power; for smaller coils No. 18 and even 20. It should be in one length, in case of any accident occurring at a join, and also to avoid irregularity of form which is apt to be caused by a joint. The question as to the advantage of two or three layers is of the same order as that of size; it is a matter of resistance, current, and space occupied: the balance is in favour of two layers. This also brings the two ends to one extremity; if three are preferred, the end of the wire must be brought out and carried back under the stand in mounting.

1125. For general purposes it may be wise to err on the side of using wires *too small* rather than the reverse, because that error partly compensates itself by the greater number of turns, and may be corrected in working by using an extra cell or two, but this does not hold with really good coils. *Ampere turns* magnetize, and so far it matters not how they are obtained: but here the object is to get the energy into the secondary wire, and as the energy charge of the core will take the most perfect path, the result depends on the relative E M F, which can be generated in the two wires available as well as on the resistances of the two available circuits. The E M F depends on the *number of turns*; therefore the more there are in the primary, the greatei the tendency to extra current there, and loss of energy in sparking at the break. There is a great deal of mystification about self-induction in the usual treatment of this matter, but this is the simple and natural explanation.

1126. When winding, place the core in the frame with the *b* end to the left, as the wire commences there; tie the wire firmly to it with a sufficient length for connection, and wind up as firmly and closely as possible, turning the handle upwards to form a right-handed helix. When the layer is completed, fill up the furrow between the wire with a soft cotton cord, or stout knitting cotton, then bind over firmly with a strip of dry silk or silk binding (such as the drapers sell as flannel binding), to prevent any accidental contact by chafe of the wires. Now wind the second layer, and secure it in the same manner. It will be wise now to test the resistance of the wire, which should be slightly greater than before winding: if it is less, there is contact somewhere, which must be remedied by unwinding. The core and primary should now be warmed and well soaked with melted paraffin, unless it is preferred to leave this till the coil is completed.

1127. *Insulating Tube.*—The core and primary are now to be inclosed in a tube as shown by *e*, Fig. 102, which requires to be thicker at the ends than at the middle, as drawn, because the great risk is a discharge by sparks to the primary, or core, which offer a good circuit. An ebonite tube is usually recommended, but it is costly and difficult to fit exactly to the primary without waste of space. Such a tube can advantageously be built out of the *thinnest sheet ebonite.* Measure the proper size with a piece of paper cut to fit tight; cut out a piece of the ebonite, which is best done with a sharp point, or a tenon-saw drawn over the surface; hold it before a fire till it softens, and bend it over the coil, binding it with a tape till cold; then secure the joint with shellac, and add a second cylinder, breaking joint at the opposite side: in a large coil several such layers should be used. Three disks of the thin ebonite are to be cut, with central holes to suit the position, as shown, and slipped upon the cylinder, which is then thickened up at the ends by shorter cylinders, as shown. When dry these may be turned down to a regular curve, if desired, or the disks being set in position, a strip of paraffined paper may be wound on to the desired thickness, as directed in the winding of the secondary. In disks 1 and 3 there are to be holes through which a length of the secondary wire is passed, as shown. In small coils a single disk will suffice; in larger ones others are to be added so as to leave no space wider than 2 to 3 inches, but so as to keep an even number of spaces. The disks should be thickened alternately at the middle and edges, so that the thin part is where the wire passes from one compartment to the next, that is to say, where the difference of tension is least between the neighbouring portions of wire. There are two ways of thickening disks: another disk of sheet ebonite may be cut of the proper size and rasped away at one edge, and cemented with shellac on each side of the principal disk; or disks of paraffined paper may be cut and added at intervals as the wire is wound on, which is readily done by cutting a slit in each so as to slip it on. The first plan is preferable when the thickness is in the centre.

1128. The two end-pieces may be made of ebonite, but well-baked mahogany saturated with paraffin will answer. The inner faces may have a recess cut in them to contain a circle of thick sheet ebonite where in contact with the wires, and if desired, a casing of thin ornamental wood can be used to cover the real ends. In most coils these ends are circular, with a flat face at the lower edge; but in Fig. 102 they are rectangular, in order to carry the terminals and discharger. Whichever plan is preferred, they are now to be fixed firmly upon the insulating tube so as to inclose within them part of the primary, as shown, forming a complete reel. The insulating tube should be carried to the end of the core (instead of being cut off to the ellipse, as shown in the figure), so that the ends may be fixed securely upon it.

1129. *The secondary wire* is to be laid with its turns parallel to those of the primary, and as many turns got into the space as consists with the other essential conditions. The size of wire depends upon the object aimed at. A full bushy spark depends on *quantity*, and this on the size of the wire; length of spark depends on *tension*, and this upon the number of turns; the size of wire will range between Nos. 35 and 40. The coil is to be arranged in the winding stand as before, with the *b* end to the left, with pieces of wood or cork in all the spaces, except the end 3 *b*, to support the disks; the end of the wire is to be passed through a hole in disk 3, and secured in the space 2, 3 for joining to the wire which is to fill that space, and then wound in the space 3 *b* so as to form a helix corresponding to that of the primary, with the precautions as to insulation described § 1130, filling up to the elliptic outline, and leaving the end out, for connection to the terminal. Next fill up the space 1–2 in the same way. Now *turn the reel end for end* in the frame, bringing it as it is in Fig. 102; and fill up the other two spaces, joining the wire to the ends left in the spaces for that purpose; then the spires will all be in the same direction and be a continuous helix, when the two ends at partition 2 are soldered together.

The object of this construction is to concentrate the stresses at the ends of the coil, where insulation is most easy, and to secure the most perfect insulation where most required. In the common construction with the secondary wound backwards and forwards from end to end, as in Fig. 105, it is obvious that a great length of wire intervenes between the proximate ends of two separate layers, and there is great risk of a spark breaking through the insulation.

1130. *Insulation of Secondary.*—The wire itself should be silk-covered; it should be well baked, layed on while quite dry, and is better for being paraffined. Between each layer an insulating film is spread, which is usually made of several thicknesses of guttapercha tissue, but it is doubtful whether good paper paraffined, such as is used for the condenser, is not better. The best mode of applying either is to cut it in long slips half an inch wide, fix the end over the end of wire, and wind spirally, so that the strip overlaps half its width. On reaching the end or partition, the space should be perfectly filled with softened paraffin; the strip should then be folded back on itself close to the wall of the space, and wound spirally back half-way up the space, so as to give two thicknesses of paper where little insulation is needed, and four where it is most required. In long spaces or undivided coils, the strip should be returned two-thirds of the length, and again for one-third, so as to have six thicknesses at the dangerous ends. If paraffined paper is used, the final process will make all secure, but if guttapercha is employed, it will be an improvement to paint round the ends at each layer with shellac cement. Some paint the whole wire thus when laid, but this renders it next to impossible ever to remove the wire if desired. Guttapercha dissolved in benzole or in oil may be used instead of shellac.

When the coil is completed, similar external insulation should be employed, filling up the outer dotted line, Fig. 102. This should be of an air-proof nature, such as paraffined paper or solid guttapercha, otherwise the guttapercha sheet is apt to be destroyed by the action of the air. If paraffin insulation is used, the coil should be slowly warmed for some hours, and then saturated with melted paraffin before applying this external covering.

1131. The *continuity of the wire* should be carefully watched throughout, as described, § 1152 (7), or at least tested as each layer is completed, lest any break should occur unnoticed. It is also a great advantage to test the growing inductive action as the coil progresses, which is one reason also for building it on the core itself. At the earlier stages this may be tested by a suitable galvanometer, connecting up a single Daniell cell to the primary, with a hand contact key interposed, and observing the deflection produced on making and breaking contact: when the coil has so far progressed as to give sparks, a discharger may be used, and the break key should have the condenser attached. The increasing spark can be thus watched, and any accidental failure of insulation at once detected before it is covered up. The construction of a large coil is a matter of so much labour that these precautions are of great consequence.

1132. *The Break.*—The construction of this is simple, but involves important principles. Its objects are (1) to close the battery circuit fully, with as little resistance as possible. This requires a good contact surface at the platinum points and a strong pressure of the spring. (2) To maintain the contact till the core is fully magnetized. This requires the resistance of the spring to be just sufficient, so as not to allow the armature to be moved until the full magnetism is approached: for this reason it is desirable to place the point, as shown, at some distance down the spring, which then assumes a curve before actually destroying contact. To assist this the spring may be of taper form, thinning away towards the upper end. (3) to break contact as sharply and completely as possible.

1133. The armature must be of the best soft iron and as massive as the core itself; it in fact acts as a prolongation of the core, and assists the inductive actions. The construction is shown *b*, Fig. 102, the spring is secured to a brass bracket, which carries also a set-screw, by which the distance between armature and core and the resistance of the spring are adjusted. A similar but higher bracket carries a screw pointed with platinum, and provided with a loose set-nut to prevent its shifting with the vibrations. The platinum should be soldered in position, but care must be taken that no solder runs over it. A hole should be drilled in the point of the screw, and tinned by means of a pointed wire, and the platinum wire entered firmly in. The piece on the spring may be a piece of thick wire, in which case a hole should be drilled in the spring, in which a reduced end of the platinum may be entered, riveted up, and touched with solder on the back. A piece of stout sheet platinum may be used, in which case the spot it is to occupy should be tinned, the platinum placed, and the iron carefully applied round the edges. Platinum requires to be moistened with flux to enable solder to take readily.

For some purposes a break worked by hand or mechanism is useful, and consists of a spring pressing on a ratchet-wheel revolved at a fixed rate. This may be interposed between the coil and battery, the ordinary break being screwed up.

1134. *Mercury Break.*—The mere contact of the point against the spring makes imperfect circuit, so that for large coils a better contact is obtained by using a wire dipping in and out of mercury; it may be moved in several ways: (1) a copper wire can be attached to the top of the vibrating spring of the usual break, Fig. 102, and bent over so as to dip into a vessel of mercury; (2) an iron rod may be fixed on the top of a wooden pillar: a spiral of copper wire of the same gauge as the primary wire is wound loosely around, so as not to touch the iron, and to extend to twice its length: the upper part of the spiral is connected to the circuit, while the lower end is bent out and made to dip into the mercury cup. The passing current magnetizes the iron and contracts the spiral so as to lift the end of the wire out of the mercury.

The mercury cup should have a copper rod in its bottom, by a screw on which its height can be adjusted: the mercury may be rendered less mobile, by having silver dissolved in it, and it should be covered with alcohol, or with paraffin oil; this serves two purposes: it prevents the mercury scattering, and by its higher stress endurance prevents the formation of the spark and stops the extra current: the end of the wire should have a stout platinum wire fixed to it, and the cup should have a cover with a hole in which the wire can play freely. Such a break may be made independent of the coil current by being worked from an independent cell, or mechanically, in which case two mercury cups may be used, with a bridge of wire moved by the apparatus and making actual break in only one of the cups.

1135. *The Condenser* is made as described § 84, but for small coils, good paper well dried will answer. The area of foil depends upon the battery power to be used, increasing with this: if the condenser capacity is too great, the spark is reduced, possibly by the action referred to § 109. The best way to find the proper size is to connect it to the coil while making, and test the effect of each added pair of sheets on the break and the spark produced.

1136. Oil insulation has recently been applied to condensers by Mr. Swinburne, in a manner which promises good results: he uses "butter-skin" paper between the foils; this is a fine tissue paper, prepared with paraffin. When the condenser is built up he heats it for a long time, under pressure, and then allows paraffin oil to enter and fill up the whole space. Of course there must be a casing which prevents escape of oil.

1137. The two faces are connected, as shown Fig. 102, to the spring and screw of the break. Its function is to absorb the "extra current" of the primary, as is shown by the reduction of the spark, which would otherwise destroy the platinum. This enables the core to be quickly demagnetized, and the charge reinforces the battery current at the next close of the circuit. The effect is to prevent energy being uselessly expended, and to transfer it to the secondary wire as explained, § 958, and the capacity needs to be just equal to doing this, and the better the break does its work the less the capacity needed.

1138. *Simple Construction.*—Very effective coils may be made by careful work, depending upon well-selected paper, § 84, and paraffin: success depends upon securing absence of moisture by baking at intervals, which is best done in a *water oven*. This can be constructed of a tin cylinder standing in a saucepan of water; a little hole in the cover of the cylinder should have a piece of pipe fixed to it, so that by holding a piece of cold glass against its end, the absence of condensed moisture will prove dryness. The core being made in a paper tube as described, § 1122, the ends should be fitted firmly on it, the primary wound on, and the insulating tube commenced by winding on strips of paper of which the first layer or two may be pasted with fresh flour paste; this is allowed to dry and well baked: the secondary is to be wound on, and insulated as in § 1130, with paper strips not paraffined: the finished coil should be cased with paper strips, pasted here and there and at the ends to hold them in place, then baked slowly till quite dry, boiled till fully soaked in the paraffin, and allowed to cool slowly. It is well to make the coil in this way with thin inner ends which can be made of paper pasted together and dried and made to the exact size required: the coil, thus complete in itself, can then be mounted in ends of woods or other material in which recesses are turned to receive it. This plan is better than using strips of paper paraffined first, as this is apt to be brittle; but if this is preferred, the wire should first be baked and soaked in paraffin, or run through it as wound on: the paper in this case should be warmed as it is applied, to diminish its stiffness and brittleness.

1139. *Disc Coils.*—The subdivision shown in Fig. 102 is sometimes greatly extended, the sections being only an eighth of an inch wide. In this case they should be made in pairs upon the same principles as are explained § 1129; they should be made to slide over the primary inclosed in a straight tube, and the increasing thickness obtained at the ends by putting additional material in before the wire. The best process is to make a mandril of the proper size with two metal cheeks of the size of the coil, one being movable: a disk made up of paraffined paper is placed against the fixed cheek, then the cylinder of required thickness, then another disk through the inner part of which an end of the wire is passed: against this the other cheek is fixed so as to form a narrow reel. The wire, which should be paraffined, is now run on so as to fill this space, when boiling paraffin can be run in, which cooling will make a solid mass.

The movable cheek is then to be taken off, another cylinder and disk added so as to form another reel; the mandril is then reversed, fresh wire joined to the end left on at first, and run on as before. This pair of sections has two ends on the outside, and can be placed on the primary, to be followed by others similarly constructed, and when complete, the outer ends of the wires are joined together in one continuous circuit, the whole warmed and treated with paraffin, as in § 1138. It will be seen that on this plan the disks replace the insulation between the layers, because in these there is comparatively little difference of potential.

1140. DIMENSIONS OF COILS.—It is not possible to give exact figures to attain definite results, as much depends on care in the making; as a rule, 1 lb. of wire of No. 36 size should give 1 inch of spark; but beyond 18 inches in length, large coils rarely come up to this ratio. The following figures may be useful; they are taken from records of coils actually made.

Spark.	Core.		Primary.		Secondary.		
inches.	length.	diam.	gauge.	layers.	gauge.	lb.	oz.
¼	4	·5	20	4	36	0	3
..	3	·75	20	3	40	0	3
½	5	·7	18	2	36	0	8
1	6	1·	16	2	40	1	0
..	9	·75	16	3	36	1	0
2	9	·75	16	2	36	2	0
3	12	1·	16	2	38	3	0
3½	9	·75	16	2	36	3	3
6	18	1·5	13	3	36	5	10

The two last are disk coils, and the last is that of Mr. Brown, of which fuller particulars will be found, § 1147.

The condensers require about twenty sheets of foil for small sizes, rising to fifty or sixty, the size being such as will go under the base of the instrument.

1141. THE LAWS OF COILS.—Many people think that force is generated in induction coils; but like all other apparatus they are mere converters of energy, and always return less than is supplied to them. The principles involved will be found in § 504 and throughout the chapter on current.

1142. The effects of a coil depend upon the size of the secondary wire, and its length, § 1129. *Size* or *thickness* of spark depends on the *thickness* of the wire: *length* of spark depends on *length* of wire; the laws are in fact the same as those of batteries and of the heating of wires. We may regard each turn of wire as an electromotor analogous to a cell of a battery, or to a thermo-electric couple. At each section of the coil equal E M F is developed in each turn, whether close to the core or at the outside of the coil; but the distinction must be remembered between the E M F developed *in* the turn, and the effect produced externally *by* the turn: this will correspond to the actions of a large or small cell of equal force, and, therefore, the inner turns exert more energy than the outer, because their own resistance is less in the ratio of the lengths.

1143. So also the E M F developed *in* the turn is independent of the nature of the metal of the wire, but as the *effect* produced depends on the resistances as well as the E M F, wire of high conductivity ought to be used; it will also develop less internal heat. It is, however, a question whether iron may not form an exception to this, because being magnetic, it would form part of the outer field of the core, increasing the permeance, and it would absorb energy in being magnetized, which it would give up within itself as current, but it is doubtful whether this would counterbalance the disadvantage of the extra resistance.

1144. Coils may be united as cells are, and upon the same laws, and it would seem that more effect would be obtained from the same materials and currents applied in four coils of a foot long than in one single coil, but coils to be so coupled would require very perfect insulation. They may also be joined in multiple arc, and so increase the quantity, or thickness of spark, but the coils must be similar in construction and force. In these cases each coil should have its own battery, but all the breaks should be screwed down, and a separate single break inserted in a common return wire so as to act on all at once.

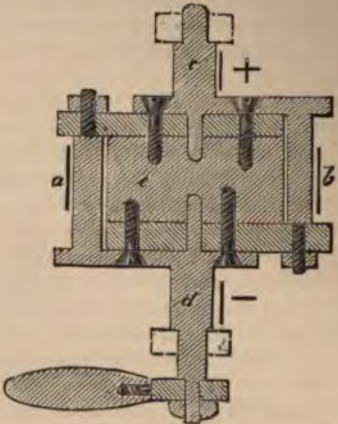
1145. Mounting Coils.—In Fig. 102, *d* is a slab of glass, ebonite, or prepared wood, fixed upon the ends of the reel, forming a frame the sides of which may be advantageously closed with glass, so as to protect the coil from damage by dust and damp; a tube in the middle of *d* carries a rising table of ebonite; and the two pillars + and − connected to the terminals of the secondary, constitute a universal discharger: they are, in fact, an elongated binding-screw, to which wires to any apparatus may be attached. They terminate at the top with a spherical socket, forming a universal joint. The rods, carrying wires, &c., slide in a tube, so that their distance, position, &c., are under perfect control.

In most coils these pillars, or insulated binding-screws, are placed on the stand at the end or the side of the coil, but the arrangement shown is much more convenient for large coils. The two ends of the primary pass down through the stand outside the end of the reel at *b*, the inner is connected to the spring of the break, and by it to the binding-screw, as shown: the outer end goes direct to the other binding-screw.

1146. It is better to have a commutator on the stand to reverse or cut off connection with the battery. The best construction is shown full size, Fig. 104, *e* is a circular or elliptic block of wood or ebonite, with a cheek on each side projecting beyond opposite ends of the diameter to afford a fastening for the metal portion. This consists of two similar pieces of brass, *c d*, which may be built up of several parts or cast in one, as shown. These form the axis on which the apparatus moves; each is supported by a metal bracket, connected to a spring + or − by which the current enters and is carried by *c d*, to the springs *a b*, by which the current issues, that one becoming positive against which *c* is turned: when the handle is vertical neither spring is touched and the current is cut off. The springs should be fixed to small brackets with stems to pass through the foundation plate of the instrument, and are to be used in place of the principal binding-screws for all connections directed to be made to these.

1147. Noted Coils.—(1) *Rhumkorff* constructed some, containing about 60 miles of secondary, which with 1 Bunsen cell gave $3\frac{1}{4}$ inches spark, and 16 inches with 7 cells.

Fig. 104.



(2) *Ritchie* made one for Gassiot, the core 18 inches, $1\frac{3}{4}$ diameter; the wire covered with guttapercha $\frac{1}{10}$ thick; the primary, 9 guage, 150 feet in three layers. The secondary in three cylinders, each 5 inches long, made of guttapercha $\frac{1}{10}$ thick; the wire of the middle one, 32 gauge, 22,500 feet long; the others of 33, each 25,575 feet. There are three condensers, of 50, 100, and 150 feet, capable of combination. With 5 Bunsens, each coil gave a spark of 5 inches; the three gave $12\frac{1}{4}$ inches.

(3) *Siemens and Halske.*—Made with a great number of partitions of sheet ebonite, containing 80 miles of secondary, and gave sparks from 1 to 2 feet in length.

(4) *Yeates'.*—In two compartments; core 22 inches by $1\frac{1}{4}$;

primary, 12 gauge in 2 layers; secondary, No. 36, in 55 layers, making 55,000 turns, insulated with guttapercha tissue and paraffined paper, 10½ miles in length, and 10½ lb. in weight; condenser 66 sheets of foil 11 × 29, with paraffined paper. With 5 Grove cells it gave 12¾ inches spark.

(5) *Ladd's.*—Core, 1 foot long, 1·8 inch diameter; primary, 12 gauge, 50 yards in three layers; secondary, 3 miles, No. 35, in layers from end to end, each separated with five or six sheets of guttapercha tissue; condenser 50 sheets of foil 18 × 8 on varnished paper: gives 5 inches spark with 5 Bunsens. One constructed for Dr. Robinson, with two secondary coils, each 5690 yards, or together, 6 miles 820 yards, is said to give sparks 2·04 inches with one cell; 5·06 with two; 6·45 with three; 7·65 with four; and 8·38 with five cells.

(6) *The Polytechnic.*—Length from end to end, 9 feet 10 inches; diameter, 2 feet; weight, 15 cwt., containing 477 lb. of ebonite. The core 5 feet long, of No. 16 wire, 4 inches diameter, 123 lb. The primary, 145 lb. of 13 (·0925) 3770 yards, making 600 turns in strands of 3, 6, and 12 wires; total resistance, 2·2014 ohms.

The secondary, 606 lb., 150 miles long, and resistance 33,560 ohms, on an ebonite tube ½ inch thick and 8 feet long, the coil itself occupying 54 inches in the middle of the tube.

The condenser was in six parts, each containing 125 square feet of foil. The coil gave 12-inch sparks with 5 large Bunsens, and 29 inches with 50 cells. Particulars of experiments may be found in No. 513 of the *Chemical News*, Sept. 24, 1869. This coil did not endure long and is broken up.

(7) *Spottiswoode's.*—This, made by Apps, has two inducing systems, (1) for long thin sparks, core, 44 × 35 inches, weighing 67 lb.; primary, 660 yards of ·096 wire, weighing 55 lb., in 6 layers and 1344 turns, with resistance 2·3 ohms. (2) Core, 44 × 3·8 inches, weighing 92 lb. Wire, 504 yards, weighing 84 lb., in 3 layers, each forming a distinct circuit.

The secondary is 280 miles long, with resistance 110,200 ohms. It is in 4 sections, with 200 layers in each, and a total of 341,850 turns.

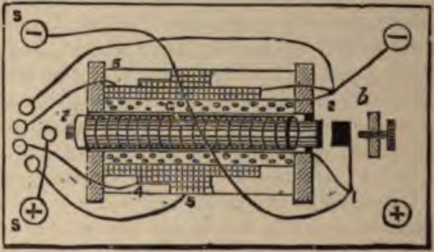
The condenser is 126 sheets of foil, 18 × 8¼ inches, separated by varnished paper ·011 thick. With 5 quart Grove cells a spark of 28 inches is obtained, 35 inches with 10, and 42 with 30 cells.

(8) Mr. J. Brown of Belfast has made a coil on the disk plan, giving very good results. The core, 18 × 1·5 inch of No. 22 charcoal wire, has a primary of ·1 wire, 73 yards in 3 layers, making 460 turns, in a vulcanite tube ¼ inch thick.

The secondary is 5 lb. 5 oz. No. 36, and 7 oz. No. 35, 5½ miles long, with 5310 ohms resistance, wound in 44 disks, each about 3-32nds or ·1 inch thick; those in the middle, 3 inch internal diameter and 5·5 external; at the ends 3·25 and 5. The wire was wound on through melted paraffin and the disks made of 4 thicknesses of thin unsized paper, and the secondary only occupied 5·5 inches of the middle part of the core. The condenser is 48 sheets, 9 × 6½, separated by 2 sheets of paraffined paper. Sparks of 5½ inches were obtained at first, but by covering the secondary with 3-8ths of paraffin, they were increased to 8 inches with 5 Groves.

1148. Medical Coils.—These depend on the same principles as spark coils, but give pulsations of comparatively small force but larger quantity. For this purpose the "extra" current of the primary itself should be utilized, and stouter secondary wires employed. A great variety of arrangements are employed, vertical and horizontal. Fig. 105 shows the most convenient plan, in which a current in one direction only (that of breaking circuit) is given off. By means of the commutator, which employs different lengths of wire, the energy can be varied, and the sliding tube over the core controls the force of the shock produced, with the greatest nicety. The action of this tube is, practically, to shorten the core as far as it covers it, so far as its inductive reactions are concerned, by enabling the induced current to form in the tube itself instead of in the wire outside it. The following particulars relate to a coil 6 inches long in the core.

Fig. 105.



1149. On a mandril about an inch diameter, slightly tapering, make a pasteboard tube of three or four thicknesses of brown paper, and form a reel by gluing on this two turned ends of 3 inches diameter, leaving a space of 5 inches between them. There should be a groove on the inner faces of the ends towards the edge which is to be secured on the stand (and which is there slightly flattened) for the wire ends to lie in. Lay on four continuous layers of No. 18 cotton-covered wire, and bring out several inches of the ends, calling the inner end 1, and the outer end 2. To 2, just where it leaves the coil, join a length of No. 22 or 24 wire which will commence the secondary; when four layers of this are placed, bring out the end, calling it No. 3, and joining to it, as before, a continuation of No. 26 or 28, calling its outer end No. 4; to which, if desired, a further length of finer wire may be added. All the wires may be cotton-covered and should be soaked with paraffin before or after laying; but silk-covered wires give higher effects from smaller dimensions, less wire, and lower battery power.

1150. A brass tube *t* is cut to slide freely within the primary tube, and at one end a thin piece of metal is soldered within it, to serve as a stop; a bundle of soft wires is then packed within the tube, and a ring fitted upon its inner end to abut against that just described, and prevent the tube from being drawn entirely off the core by the handle *t*, fitted to the tube itself at the same end; the other end of the core is then passed through and secured to the farther end of the coil *b*, by wedging and cement, and trimmed off smooth to work the break *b*, which is similar to that described, § 1132. Fig. 105 explains the connections: + and − are the battery screws; + is connected to the screw of the break, and the inner end of the primary, 1, is connected to the spring, which is also connected to *s* −, one of the secondary binding-screws; the end 2 of the primary is connected to − for the battery circuit, and also to the first stud of the commutator for the secondary circuit. The secondary wire is shown in stages and numbered; it begins at 2, by being soldered to the end of the primary; the ends of the various lengths, 3, 4, 5, are taken to successive studs of the commutator, the central spring of which is connected to *s* +. The commutator takes up either the "extra" current from the primary, or that with the added effect of the lengths of secondary, according to the stud on which the spring is placed. As arranged, that secondary binding-screw will be +, which is on the same side as the primary screw connected to the + pole of the battery: the current taken up is in the same direction as that of the battery, *in the coil*, therefore if the inner end of the wire is so connected as shown, the outer end is of course the + conductor from the coil. The effect of this mode of connection is, that when contact is made, the battery offers a path of much lower resistance than the body; therefore the current induced at making contact does not pass through the body which, transmitting only the current of breaking circuit, is subjected only to the influence of a current in one direction. This is considered of great importance in some cases, but it is extremely doubtful whether the action of coils is a truly electrical one at all, as to its medical effects: it seems probable that these are principally due to the muscular contractions and releases, to the internal frictions and motions thus produced, and consequent disturbance of congestions, and stimulation of the nerves. Care should be taken to avoid violent shocks or pain, and it is important that the break should work with a soft hum, not with violent jerks. This is why the action of coils is superior to the more jerky shock given by magneto machines.

1151. *Small coils* may be made to be carried in the pocket, such as are made by Gaiffe of Paris, and others, worked by one or two chloride of silver cells, § 223, fitted up in ebonite cylinders with caps to screw on, and working by the liquid soaked up in paper between and round the plates. In these the connections are made by studs of metal pressing against springs fixed on the inside of the outer case; the vibrating spring of the coil is similarly attached to the case, and the coil itself is loose and makes its connections by the act of placing in the case; those of the conductors are made by split wires, at the end of the flexible wire cords, which are pushed into metal tubes let into the case, and the graduating tube works through a hole in the side. Such coils may be made even 2 inches in length, with primary of 22 wire and secondary of 30, all silk-covered and paraffined; the vibrating spring being made of thin watch-spring.

1152. MANAGEMENT OF WIRES.—This is of great importance, especially in constructing coils. The greatest care is requisite, for there is little satisfaction in spending much time and labour in winding up a great length of wire, and then discovering that there is a break in it at some unknown point. The following precautions, though very troublesome, will well repay the trouble.

(1) Test each reel of wire for continuity, by sending current through it and a suitable galvanometer: if the means are available the resistance can be noted.

(2) If not continuous, wind upon a fresh reel, passing the wire through the fingers and carefully watching it. It is best to mount the reels on metal axes against which a spring presses, soldering the beginning of the wire to the rod. By this means a permanent test can be kept up, and measurement of resistance, length, &c., can be made at any time.

(3) It is desirable in many cases to paraffin the wire. It should be first well baked till all moisture is driven off, a

while hot should be dipped into the melted paraffin, or this may be poured over it. For fine wires the paraffin may be thinned with turpentine, or benzoline, which will prevent the wire from being much enlarged. It is desirable to warm the reel of wire when it is about to be used so as to soften the material.

(4) The paraffin may be applied while winding, by passing it under a roller at the bottom of a tin vessel containing the paraffin kept melted, and through a hole in a cork as it leaves the vessel to remove excess; the wire ought to be well dried just beforehand.

(5) The resistance of the wires should be taken, and noted; then by measuring that of a known length, the length of wire used for any purpose may be nearly ascertained.

(6) In winding coils, &c., it is desirable to ascertain the number of turns the wire makes: this may be done with a counter, easily made up from such wheels as are used in gas-meter indices. This may be actuated either by an attachment direct to the end of the axis of revolution, or by an electro-magnet actuated at each revolution by an ordinary circuit-closer. The best plan is to have a worm cut on the winding axis, to work in a wheel with 100 teeth, then the rest of the work can be fitted up with wheels as used in meter indices.

(7) With fine wires a constant test for continuity should be maintained. The beginning of the wire of the instrument should be connected to a metallic cylinder on the axis, as in (2) above. The spring and that of the wire reel are connected to a galvanometer and a battery: if a commutator is used, the current need not be continuous, but a test current can be sent through at intervals. This checks the insulation, as any accidental contact will reduce the resistance, which ought to increase continually as the wire is strained by winding.

(8) All joints should be carefully made, stripping the wire, cleaning it, tapering the ends and tinning them; fine wires should then be carefully twisted together and soldered, which is best done by means of a piece of No. 10 copper wire in a handle. If this wire crosses a gas flame, the point beyond (being well tinned) will act as a convenient soldering-iron for very fine work. The joint should be carefully covered without increasing the size of the wire; this may be effected by rubbing the warmed wire with a stick of cement made of guttapercha and resin melted together. Only resin should be used as the flux in soldering wires.

1153. **Transformers.**—These are simply induction coils arranged to work with large currents: they are made in two classes.

(1) *Step up* transformers, where as in ordinary coils a large current at low voltage is converted into a smaller current at correspondingly higher voltage.

(2) *Step down* transformers, where the primary circuit from the source at a high voltage is a fine wire circuit of many turns, and the secondary wire of few turns delivers a larger current at a lower voltage.

The analogy is complete to the effect of gearing either 1, a large wheel to a small one gaining speed, or 2, a small wheel into a large one at less speed.

1154. In both, the primary magnetizes the core and sends its energy into it, while the secondary, large or small, receives back that energy and sends it into a new distinct circuit, by means of the current generated by the action described, §§ 498–501.

There is, however, this difference between transformers and induction coils, *there is no break:* the coil works with an intermitting current, broken circuits and resulting sparks; the transformer works with an *alternating* current and both circuits always closed.

1155. As a consequence the current is an undulatory one of alternating direction, but the only losses of energy are, 1, the heating of the two wires; 2, hysteresis in the iron; 3, Foucault currents. The remaining energy taken from the primary current appears wholly as electric energy at the terminals of the secondary, and therefore the efficiency may be as high as 96 per cent.

1156. But an important consideration comes in here: the makers efficiency is reckoned under the best conditions, at full work: this falls off as the ratio of actual work to full work diminishes. This is shown by figures from experiments on Westinghouse transformers by Messrs. Duncan and Hasson in America. A 20 light converter gave

No of Lamps.	Volts.	Watts in Secondary.	Loss of Watts in Secondary	Loss in Iron Watts.	Efficiency.
20	48·8	952	106·0	95·2	90·0
15	52·2	817	104·0	108·9	87·6
10	50·3	506	101·0	99·2	83·3
5	51·44	264	109·4	108·2	70·7
0	52·3	0	110·5	110·5	0·

But the important point is that the primary circuit is *always* on; the loss in it and by hysteresis in the iron are always incurred, so that it is a question whether more than half of the energy expended is really returned as work: this is not charged for at the meter, it is true, but it has to be paid for in the form of a higher price per unit.

1157. It is still an unsettled question whether the iron should be an open or a closed magnetic circuit, we may call these *rod* or *ring* cores. Coils have rod cores, and the earliest practical users, Goulard and Gibbs, used them. Later on, by general consent, ring cores or closed circuits were adopted. Quite recently Mr. Swinburne returned to the open circuit with his Hedgehog transformer, which he claims to give a higher all day efficiency.

The *closed core* has the advantage of higher permeance and induction, § 963, but it gives a greater loss by hysteresis, as the closed circuit does not give up magnetism so readily.

The *open circuit* needs larger current, more ampere turns to bring iron up to the same induction, which means loss of work in the wire, to set against diminished loss by hysteresis.

1158. The relative losses by hysteresis and Foucault currents in the iron is a disputed point, Mr. Mordey found with iron only ·001 inch thick that the current loss was three times as great as hysteresis, while Mr. Swinburne considers it as small, and others find it about one-tenth of the hysteresis.

A valuable paper was read 19th January, 1892, to the American Institution of Electrical Engineers, by Mr. C. P. Steinmetz, on the subject of hysteresis. He finds that the loss per cycle varies as the one-sixth power of the magnetization, and may be expressed as

$$H = \eta B^{1\cdot6}$$

H being the energy in ergs per cycle per cubic centimetre.
B the lines per square centimetre.
η a coefficient variable with quality of iron, in his experiments = ·002.

He also says that, contrary to general opinion, the coefficient of hysteresis on open circuit is ·00393, while that of closed magnetic circuit is ·00335 which seems to require further examination.

1159. It is of importance to prevent any risk of deficient insulation letting the high primary voltage find its way to the secondary circuit: this is done by inserting a sheet of metal, connected to earth, between the two wires; any leakage would increase the primary current, melt its safety fuze, and cut the instrument out of circuit.

1160. *Oil insulation*, however, will prove a good protection, § 1116, and it is only necessary to place the transformers in an oil-tight vessel and allow oil to penetrate the whole of the coils: for this purpose much cheaper covering of the wire is permissible, as the real object of the covering will be only to produce a definite distance apart of the wires: the oil is the insulator as applied by Mr. D. Brooks of America to his system of conduction: resin oil being the best for the purpose.

Oil as an insulator, is likely to play a very important part in the coming developments of high tension electricity: its chief advantage is probably not so much its specific insulation value, or resistance to breaking down, as its ability to immediately close up whenever it does break down; also it is homogeneous, not liable to physical injuries or the formation of those fissures which are the draw-back to solid paraffin.

From a paper read by Prof. D. E. Hughes to the Institution of Electrical Engineers, 10th March, 1892, it appears that he was not only the first to propose this, but patented it in 1859, and a mile of specimen submarine cable was then made to test the application to that purpose, to the automatic repair of faults. He also found at that time, as others have since, that resin oil was the most serviceable.

Mr. Swinburne says that in transformers the oil does not repair damages, but that when leakage occurs an arc forms and produces permanent leakage; other experimenters also consider that the main function of the oil is to keep the other insulation dry; cotton, jute, and other forms of cellulose being perfect insulators so long as perfectly dry, but they absorb moisture.

1161. *Motor generators* are transformers of continuous current. They were devised by Gramme to obtain high voltage from a few Bunsen's cells: he arranged two circuits upon his ring in alternate sections, 1, carried the primary current which rotated the ring; 2, carried a fine wire circuit in which current was generated. The same process has been adopted by others, as Edison, and Paris, and Scott. As suggested, § 1114, they may become important agents in transmission of energy and enable the intermittent primary current to be distributed as a continuous one at a convenient voltage.

CHAPTER XIII.

ELECTRIC LIGHTING.

1162. The study of light involves four distinct considerations: (1) The phenomena of its origin. (2) The mode of its transmission. (3) The nature of its perception. (4) The energy expended in its origin and absorbed in its perception and actions. Although it would be out of place to examine here the whole subject of light, it is necessary to clearly define these points in order to comprehend the production of light by electricity, and the economic aspect of the subject. This classification of the facts will help greatly to clear away the mystifications which have been produced by trusting to hypotheses and using them as facts, as is now so commonly done.

1163. Light is not a *thing* having any existence of its own, it is an action, a motion of vibration. In fact, light as it is commonly conceived, *has no existence at all outside of our perceptions.* The light is in the eye, it is a sensation produced by a rhythmic motion, which other organs perceive in a different form, which we may know by other names.

1164. Motion may be irregular and indefinite, or it may be rhythmic; it may be in straight lines, deflected in any direction by obstacles, as radiant energy: or it may, when due to two co-acting forces, be vibratory like that of a pendulum. Undulatory or wave motion is of this latter order, and is rhythmic; that is to say, its vibrations are of equal intervals. Thus a pendulum swings in exactly the same time, whether its swing be merely perceptible, or ranging over nearly the semicircle. But here it must be noted that this applies to the theoretical pendulum, swinging in vacuo without friction; the actual pendulum is subject to retarding actions, which reduce each successive motion, unless a force lifts it to its starting height, as in clocks. This applies to many general laws; they are related to theoretical conditions which cannot be actually realized, but can be calculated.

1165. Such a rhythmic motion we observe in the simplest form when we throw a stone into a pool of water, and produce a set of circular waves, which are reflected from the edges, and ultimately lost in an apparent confusion, which is really perfect order, but too manifold for our eyes to distinguish: we can see the waves crossing each other, neutralizing each other as they cross, yet each remaining unaffected; we can see in this, that each molecule of the water, while itself merely rising and sinking in a vertical direction, may be subjected to and transmit many stresses in different directions.

1166. *Sound* is a rhythmic motion of the particles of air and other matter, which becomes what we call sound only in our perceptions; in space it is merely a vibrating motion, which another perception translates into a succession of blows, as when we lay our finger on a sounding board. It will be understood therefore, that we can really *see* and *feel* sound, and this will illustrate the meaning of § 1163. As there said of *light*, so now we may say of *sound*, that it has no real existence. What really exists is *motion;* it only becomes sound by the perceptive action of our nerves of hearing, and it is the same with the more refined motion which our optic nerves translate as light.

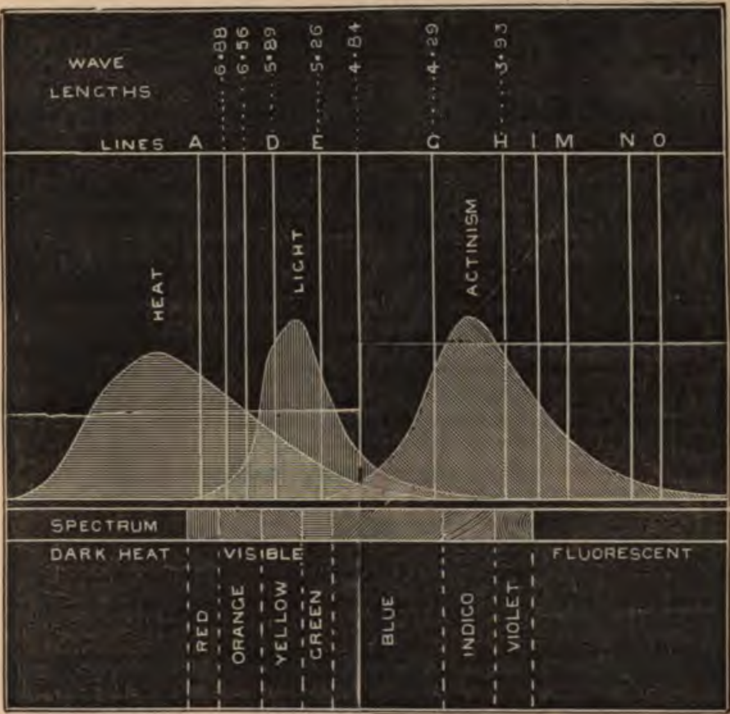
1167. *Musical sounds* are rhythmic motions, and each note of the musical scale means a fixed number of vibrations per second: the strings of a piano are each of such a weight and strain as compel them to make this fixed rate of vibration, which is then transmitted through the air, and felt by our ears. The particles of air, like the particles of water, § 1165, can thus take part in many motions, and transmit each unchanged; the quality, or *pitch* of each specific note is related to the number of such swinging motions per second, while the *loudness* depends upon the amplitude, or width of the swing; two things analogous to the length of the pendulum and its consequent period of swing, and to the height to which it may be lifted and fall through.

1168. *Sound has a reactive power* also: if we sing a note to the wires of a piano, the corresponding wire will reproduce the note; other wires which are *harmonics*, that is vibrate in 2, 3, &c., equal times, will also vibrate, but less powerfully.

1169. *Light is a motion* still more refined, so that is generally treated as a motion of the "ether." But light, as we know it, is not a simple motion, but a combination of a number of distinct wave-motions, uniting together in one grand harmony, like the united sound of an orchestra, which is the blending of a multitude of separate sounds, each of which may be distinguished among the united volume of sound.

1170. In light, as in sounds, we can distinguish the individual rhythm which corresponds to a note in music, and is a *tint of colour* in light. This analysis is effected by passing a ray through a substance which acts differently upon each wave-length, such as a triangular piece of glass, or other substance, which spreads it out from a narrow line of mixed light into a coloured band, known as the spectrum, which is simply a series of lines of light, each of a specific wave-length, blending into groups of similar shades to form the seven colours of the rainbow.

Fig. 106.



1171. This spectrum, shown in Fig. 106, may be regarded as the analogue of an opening across the front of a piano, showing the row of wires. The white vertical lines show certain exactly measured lines which appear as dark lines in the sun's spectrum, because their light is absent, having been absorbed in passing through gaseous bodies in the sun's atmosphere; the figures represent wave-lengths in ten-millionths of a millimetre, and they are measured by the thickness of the coloured films which produce them, as in soap-bubbles.

1172. These dark lines are due to the same action as that of sound, § 1168. Every substance in nature is in a motion characteristic of itself. The specific energy, § 585, of each atom is stored in this motion, vibratory, or revolutionary, acting as a vibration externally, and each atom has a specific rate of motion, just as each piano-wire has: this rate is altered in combination but is constant for each physical condition of the substance. Each atom of matter, therefore, when it acts as a producer of light, gives out its specific light, which in the gaseous state is in the form of bright lines; the line D, which is really two lines with an intermediate wave-length, being the specific line of sodium; the atom, therefore, takes up from light its own specific motion, and the sun's light (as any other), in passing through the cooler gaseous atmosphere, is sifted by the different substances it contains, and largely deprived of those particular rays. It is thus we learn what substances are present in the sun.

1173. Just as in sound it requires a certain rate of vibration, of above 27 per second to be appreciable by the ear as a note, and as, above about 3520 vibrations, sound again becomes inappreciable (and inaudible at about 24,000), these being the ranges of a seven octave piano, so it is only within a certain limit that the undulations of radiant energy are appreciated as *light* by our organs of sight, which may be said, in fact, to convert this range of radiant energy into light.

1174. It will be seen from Fig. 106 that this visible spectrum extends over only *one octave of light*, an octave being a doubled rate of vibration, and it is remarkable that the wave-lengths of the middle of each of the seven colours hold relations corresponding with those of the musical gamut; but what we are concerned with is that the spectrum of an incandescent solid shows, first, a range of rays which do not act as light, then the graded lights or colours of the spectrum, and, finally, a further range, invisible as light, but producing chemical effects. These are even capable of becoming visible when received upon *fluorescent* substances, such as sulphate of quinine, which, like the harmonic notes in sound, are capable of taking up these vibrations of short wave-length, and giving them out again in waves of greater length, which then affect the eye, as, by concentration, the heat rays may be similarly transformed into light.

1175. The three shaded curves of Fig. 102 show what used to be considered as distinct forces, heat, light, and actinism. We know now that no such distinctions *exist in the rays themselves;* the distinction lies in the *substances which absorb the rays*, and the different effects produced. Thus, the actinic spectrum represents really the rays which were chiefly absorbed by the silver salts first used in photography; hence the "spectrum" is a product of its conditions, not really drawn to scale according to wave-lengths, and the "dark spectrum" has been traced to six times the length shown, and the "ultra-violet" actinic range depends entirely on the means at our disposal for observation.

1176. *The new theorists*, without any such means, extend the dark spectrum down to what we may call the "absolute zero" of sound, through their imaginary electric and magnetic waves, §§ 883–7. A remark by Prof. Hertz (who is asserted to have proved the theory) upon Clerk Maxwell is thoroughly suited to the whole of this school. He says, 'Electrician,' 24, p. 457, "Unhappily, Maxwell oscillates too often between the reality of facts, and the conception of purely hypothetical ideas. . . . It is clear that such a method does not satisfy the mind, and leaves a prejudice that the result, and the conclusions drawn from them, are not correct." Possibly it is a "prejudice," but may it not be a true *deduction*, for Hertz has shown between the two parts of the quotation, that Maxwell starts with the notion of forces acting at a distance, seeks the laws of the "hypothetical polarization" of the ether by those forces and ends by *showing* that it varies without them. By *showing*, Hertz apparently means that, by what Maxwell called "suitable hypotheses," he supported the "hypothetical ideas." Is not this rather like the process by which Owen Glendower asserted that he "could call spirits from the vasty deep"? and is Hotspur's criticism thereon a mere "prejudice"?

1177. *Optical theorists always treat light as a phenomenon of the ether*, and here comes in the essential importance of the classification, § 1162. The ether was imagined in order to account for (2) the mode of its transmission, and it cannot be too often or too strongly insisted that this is the total sum of our knowledge about the ether. All the rest is *negative*, we know that it has no gravitation force or it would collect round the planets and light would not follow straight lines in space; we know that it offers no frictional resistance to motion, and does not absorb energy in transmission. Now these are the functions upon which the science and laws of "dynamics" are entirely based, and yet these laws are coolly applied to the ether, and the marvellous properties it is alleged to possess are derived from dynamic considerations.

1178. All the real functions of light depend on "properties of matter." When we refract, reflect, polarize light, these are *not etherial functions at all*, they are reactions of ordinary matter upon the light; all the ether does is to transmit straight rays unabsorbed.

The light does not originate in ether: its origin is, § 1172, the consequence of a *motion of matter*, the specific motions of atoms, each giving out its own "light-notes," as each piano string gives out its "sound-notes," unalterable when once formed.

1179. Dr. Oliver Lodge is a splended worker to whom Hertz's criticism applies too well, "oscillating between the realities of facts and the conception of purely hypothetical ideas." He says in his 'Modern views of Electricity' that our systems of making light are wasteful, which is true. "We want a certain range of vibrations, between 7000 and 4000 billions per second —we can produce one or two hundred thousand"; this means the Hertz radiations so-called, § 887. "To get much faster than this we have to fall back upon atoms. We know how to make atoms vibrate, it is done by what we call *heating* the substance." But we have to treat them in compact masses and by "raising the temperature we impress upon its atoms higher modes of vibration, *not transmuting the lower into the higher, but superposing the higher upon the lower*, until we get the vibrations our retina is constructed for."

1180. Now these are the "realities of facts," but Dr. Lodge goes on to say, "and so soon as we clearly recognize that *light is an electrical vibration*, so soon we shall begin to beat about for some mode of exciting and maintaining an electrical vibration of any required degree of rapidity. When this has been accomplished, the problem of artificial lighting will have been solved." But here we have the "purely hypothetical idea."

1181. Has Dr. Lodge any evidence to offer that light *is* an electrical vibration? not a particle. Let us put his thought into relation to realities. If we realize that *light is a vibration of matter* which may be produced by many processes which release or set in action the inherent functions of the atoms, and that electricity gives us our easiest mode of producing atomic vibrations, then we *may* solve the problem of economical light.

There is little doubt that light would be produced if, by electric or any means, we could directly or indirectly set up vibrations of the proper rate. That is what we do by heat, directly, and by electricity, indirectly, in the vacuum tubes, for it may be doubted whether the light of these is not due to the vibrations set up by the collisions among the moving molecules, rather than by electrical actions. But if such vibrations were set up, is it not clear that the result would be "dissociation," the shaking to disruption of complex chemical compounds, by the actions which Tyndall proved long ago, and which are the basis of all photographic processes.

1182. *This is what Tesla is aiming at* really, though probably led by the hypothesis. His progress has been shown a few days ago in his splendid lecture at the Royal Institution, 3rd February, 1892. He has opened the way to the use of frequencies and voltage unthought of: he has shown that light-giving appliances, vacuum tubes and so on may be actuated, not as hitherto by actual currents led into them by conductors, but simply by being placed, isolated, within the electrostatic field in which rapid alternations are set up. This however was done long ago by various experimenters with coils. He used a dynamo producing some 25,000 or 30,000 reversals per second, and then by Leyden jars, and the surgings or oscillations, § 916, of which Dr. Lodge has told us so much, raised the alternations possibly to millions per second.

1183. *Tesla's ideal object* is to render the space within a room itself luminous, or rather to make the air self-luminous in its ordinary state of pressure, the ceiling and floor being condenser plates; this condition he attains in his experiments, representing them by the table and a suspended plate; exhausted air in the tubes becomes luminous: the idea is to make the whole space so by still higher frequencies and voltage.

1184. He has shown that these conditions are not dangerous, because no real current passes: and he argues that when his aim is reached there can be no danger because the conditions will be those of a bath of light. Here then we see how misleading a hypothesis may become: the whole body would form part of this field and be subjected to the incessant vibration of all its constituents; is it to be supposed that this would not prove most disastrous, even though nothing analogous to "shock" existed? Light has only a superficial action, the electrostatic field penetrates everywhere; in such a field it would be necessary to enclose ourselves in a metallic coating to escape the universal action.

1185. Tesla's tubes disprove the assertion that light *is* an electric vibration, while they prove that *vibration generates light*. In the isolated tube in the pulsating field, electric vibrations exist, the molecules of air are moving, but how? in straight lines between the two plates: this is the universal law. But the luminous rays issue, not in these lines, not at right angles to them, but in every direction in spherical waves from every part of the tube, as a *radiant* action centered from every vibrating molecule, while the field is linear between dual stresses.

These *light rays* are generated by the motions, as the circular waves, § 1165, are generated by the stone, but are no more themselves electrical, than those are stony; both are consequences of motions but not related to the cause of the motions.

1186. *Physical state* affects the action of radiant energy. Thus, § 1172 shows that in the gaseous state, in which, § 673, the relations of matter and energy are most simple, each form of matter will only generate its specific ray motion. But solids can give out rays of all orders, and, in them, the quick vibrations cannot be set up without being accompanied by all the slower waves. This explains the reasons of § 1179. In all solids the highest vibrations set up correspond to the temperature attained, superposed upon all the lower ones. See § 1239.

1187. Possibly we can form the best conception on this subject by thinking only of "energy" charged on vibrating molecules; this is mechanical "work," and so we can understand the "mechanical equivalent of heat," because heat is the measure of the energy charged upon matter in this state of motion which we call heat. *Temperature* we may regard as the *density of the energy*, and diminished wave-length is the result of, and corresponds to, increasing temperature in the radiant source. But as "light" is a sensation only, there can be no "mechanical equivalent of light." The term is sometimes used for the energy consumed in a light, or the heat which can be measured as light: but this is variable for every source. Prof. J. Thomsen arrived at the value of 12·28 foot-lbs. per standard candle-power as the "equivalent of light" itself, and others have made similar estimates: the real facts will be found § 1191.

1188. The most beautiful illustration of these principles is given by the electric current in the experiment first published by Dr. Draper. If we adjust a platinum wire to the slit of a spectroscope (whose lenses and prisms are of rock-salt or quartz crystal), we can build up the spectrum of Fig. 106 by passing a graduated current. As the wire heats, a thermopile, movable along a screen on which the spectrum is directed, will show heat at a point on the extreme left, but none on either side of it: as the wire is raised in temperature, as in § 390, heat will extend towards the right, and the degree of it will rise, as the curve shows; but this is not the point at present in view, which is, that this rise of the *quantity* is distinct from the *quality*, the wave-length belonging to the position in the scale. When the wire begins to show red, this colour will appear on the screen *alone*, and so on, as temperature rises, tint after tint will grow out like rungs added to a ladder, till the visible spectrum is completed as the wire approaches the white heat: in like manner the ultra-violet spectrum grows out as the heat is further raised.

1189. It is easy to comprehend this, when we recognize that current means molecular motion; that as current increases, motion increases, and that a motion resulting from these motions is propagated as radiant undulations in surrounding space. It follows, also, that every source of light has its specific quality, depending upon the temperature to which the light-giving body is raised, and the specific properties of that body as to the proportion in which it can generate rays in different parts of the spectrum. How can light be an electric vibration? While there are coincidences of action, § 888, because motion is a part of all, there are these differences of nature between light, and electricity and magnetism. *Light is radiant;* its lines straight, and free of all control, except by contact with matter. *Electricity and magnetism are circuital;* their lines curved, re-entering and attracted towards matter.

1190. DEGREES OF TEMPERATURE.—High temperatures are very difficult of measurement, but the spectroscope may give information on them, by enabling us to measure the heat in lines developed at these temperatures. The following table gives the best information at present attainable, from various sources:—

TABLE OF TEMPERATURES IN DEGREES FAHR.

Absolute zero −273° C.	−460°
Tin melts	+455
Lead „	620
Zinc „	793
Red just visible	977
„ dull	1290
„ cherry, dull	1470
„ „ full	1650
„ „ clear	1830
Silver melts	1832
Cast iron (white) *melts*	1920
Orange, deep	2010
„ clear	2190
Cast-iron (grey) *melts*	2190
Gold melts	2282
White heat	2370

Steel melts	2370°
White, bright	2550
„ dazzling	2730
Wrought-iron melts	2912
Platinum melts	3700
Iridium „ about (?)	11400
Flames in Hottest Part.	
Stearine candle	1725
Paraffin lamp	1890
Gas in argand	2100
Spirits of wine	2160
Gas in Bunsen (some give 3500)	2475
Gas in oxygen	2760
Electric arc	8700

The temperature of incandescent lamps is said to be 1570° C. or 2829° Fahr. rising but very little even with excess of current.

1191. *Proportion of Energy as Light.*—Part only of the energy expended in raising temperature appears as light; the ratio of this part increases as the temperature is raised, and this is the real equivalent of light, § 1187. Tyndall passed light of different intensities through a solution of iodine in bisulphide of carbon, which, while perfectly opaque, is diathermanous, or allows heat-rays to pass, while absorbing light-rays entirely. His results are:—

Source.	Absorbed.	Transmitted.	Source.	Absorbed.	Transmitted.
Dark spiral ..	0	100	Gas flame	4	96
Low red „ ..	0	100	White-hot spiral	4·6	95·4
Hydrogen flame	0	100	Electric light (50 cells)	10	90
Oil flame	3	97			

Siemens estimated that in an arc lamp of 3300 candles, one-third of the energy becomes luminous, and that incandescent lamps utilize 4–5 per cent.

1192. *Gas consumption* teaches the same lesson. If we divide the feet of gas burnt by the candle-power of the light, we find that the greater the quantity of gas which can be fairly burnt in a single flame, the lower is the quantity of gas per candle-power. The standard of consumption is a gas which, consumed in a defined Argand burner at the rate of 5 feet per hour, gives 16 candles' light. The same gas burnt in badly proportioned batswing and fishtail burners may only give 10 candles or even less. The rate of 5 feet per 16 candles is ·3125 per candle; but 250 candles can be obtained from a 60-foot burner, which is only ·204 per candle, and even better results are obtained from regenerative burners.

1193. The reason is, that the area of the flame is lowered and its thickness increased, so that less heat radiates off and the temperature is higher; this, also, is why the cylindrical flame of the Argand, cased in by the non-transmitting glass tube, gives higher efficiency than the exposed flat flame. The most striking illustration of this is the often-patented double burner: if we attach two small burners to flexible tubes, and allow them to burn side by side, we may note the light effect; now if the burners are inclined to each other, so that the flames blend in one, a great increase of light is perceived. But this increase is a delusion, for the double burner only gives the same result as a well-constructed burner consuming the same gas as these two.

The real point is, that putting that gas into two burners reduces the light it can give.

1194. *Photometry.*—The measurement of light is effected in terms of a standard, or unit light, and is based on the law of the intensity of any light being inversely as the square of its distance. The simplest mode of testing gas is by the Bunsen photometer, a graduated bar, at the two ends of which are the lights to be compared. A screen of white paper, with a greased spot in the middle, is movable on the bar, until the spot is equally undistinguishable on each side, i.e. till the two lights have equal power on it. The bar being graduated in terms of the standard, the strength of the light to be measured is read off the scale at once.

1195. *The legal unit of light power*, in the case of gas, is a spermaceti candle of six to the pound, burning at the rate of 120 grains per hour. But the candles vary in quality and in rate of burning. The French standard is the Carcel oil lamp, which equals 9·5 or 9·6 standard candles.

1196. *Sugg's Argand gas-burner* is a better standard for large lights, as it gives 16 candles' light from gas of all qualities, provided the flame is adjusted to exactly 3 inches in height; it consumes per hour to produce this flame, 5 feet of 16 candle, 4 of 20, and 2·7 of 30 candle gas, such as is produced from cannel coal.

1196A. Much higher lights ought to be used for comparison with powerful arc lamps, but the measures of these lights are of a very problematical value both on account of the difficulties of the measurement itself, § 1200, and because no arc light in existence remains of uniform strength from moment to moment.

1197. *Electric standards* have been proposed, as a platinum wire of given dimensions, with a fixed current passing: a number of these might be arranged to give a large light, but each wire would require careful adjustment as to current, because no two pieces of platinum are alike; definite alloys of platinum and iridium may yet enable the conditions to be attained. Carbon lamps could not be trusted, because of their varying value by lapse of time, and from the action of even an invisible film of carbon, § 1204.

1198. *Chemical Photometry* may prove valuable, as many reactions, such as those of photography, will give exact results. The combination of equal proportions of perfectly pure hydrogen and chlorine has been utilized in the photometer of Bunsen and Roscoe, but it really gives indications of the ultra-violet rays, rather than of true light, and in fact the actinic curve of Fig. 106 is obtained from this reaction.

1199. *The best measurement of light* will probably be effected by the comparison, not of the total lights themselves, but as Professor Crova suggested, of some part of the spectrum, such as the D line, which is present in all lights, and represents the middle of the most effective portion. If a chemical reaction of such a line could be found, and conveniently used, it would give a quantitative measure. By passing both lights through similar prisms, and using only the selected rays on the photometer, useful information would be obtained.

1200. *Powerful lights* can only be very approximately measured, because they cannot be compared direct with the standard candle, on account of the great length of bar required, and because there is an intrinsic difference in colour: even in comparing the candle and gas, with only twentyfold difference in power, and close likeness in colour, two observers will differ, and when the difference becomes one or several thousandfold, this difference is serious.

1201. ABSORPTION OF LIGHT.—In § 1188, reference is made to rock-salt and quartz. Not only have gases their specific rate of generation and absorption, § 1172, but all substances have a specific relation to different rays. Thus we have the distinction of opaque and transparent bodies, and the selective power for colours. But even *transparent* substances take toll upon the passage of radiant energy: the clearest glass takes up a large portion of the long-wave rays, as well as the ultra-violet. Thus we use glass for greenhouses, as it transmits the suns rays, but prevents the escape of dark heat: also, with a sheet of glass before the eyes we may safely look into an intensely heated furnace, and examine the actions going on. On the other hand, an opaque substance, like ebonite, permits the free passage of the rays which glass absorbs, see also § 1191, and rock-salt and quartz crystals are almost the only substances which are nearly indifferent to the passage of all rays. See § 651.

1202. *The absorbing power of glass* is of great importance.

Clear glass absorbs	10 per cent.
White ground	30 " "
Opal	60 " "

Coloured glasses, in addition to the absorption of the glass itself, take up the rays complementary to the colour transmitted, so that if we pass a light through first a blue glass and then a yellow glass scarcely any light at all will remain.

1203. In connection with this subject it should be understood that no change can be made in light once produced, § 1170, except by taking some of the rays away. We may give a tint to an arc light by burning a substance in it, thus a soda salt will give yellowness to the light; but we cannot *give* yellowness to an arc light, once produced, by passing it through anything; we may *take away* the excess of violet and make it appear yellow, but in so doing we reduce the light.

1204. Incandescent electric lights are subject to a special absorbing agent. The carbon wire, especially when overheated, gives off, in some cases, a vapour of carbon which forms a nearly imperceptible dark film upon the inner face of the glass: this thin carbon film has extraordinary absorbent powers: a piece of glass so coated, held in front of a lamp in perfect action will make it appear like a red-hot wire.

1205. DISTRIBUTION OF LIGHT.—Like all radiant actions, the intensity of light varies inversely as the square of the distance from the source. This is the necessary consequence of the fact that the *surfaces of spheres vary as the square of their radii;* each point in space is part of the surface of a sphere, formed on a radius which is the distance of the light source, and therefore as the light is divided over a total area increased as the square of the radius, the quantity available on each unit of area must be inversely as that value.

1206. This will illustrate the idea expressed § 1187. A source of light may be regarded as an agent for converting potential energy into kinetic energy, which it continually radiates away in spherical waves. This energy traverses *pure space* with little, if any, reduction, § 1177, though it is absorbed by matter under conditions explained, § 1172. At each spherical extension the wave is spread over a larger area, therefore its amplitude or height is lowered, and the energy in it per unit of area is reduced; that is to say, the *density of the energy* is lowered in proportion to the *square of the distance* it has traversed.

This is an important consideration in applying light to practical use. A light of great power may be uselessly intense at one part, and unequal to the required effect at another. As a rule also, several lights distributed about an area are better than an equal light at one part, because they break up the deep shadows a single light must throw. A very intense light is also injurious to the sight: it is said that we need not look at it, neither need a moth fly into a flame, and light draws the eye to it as the flame does the moth. Better results are obtained, throughout a space, from lights evenly distributed, than from a light of three times the nominal power at a single point. Therefore, notwithstanding the low cost per candle of arc lamps, they are unsuitable for internal uses, and less economical than the more costly incandescent lamps.

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1207. Electricity as a Source of Light.—This is no new discovery, for Davy made it in 1809, and exhibited an electric arc four inches long in air and seven in vacuo. Great also as recent improvements appear to be, there is really little more known on the subject than has been known for many years; this may be seen from King's specification published in 1846. But electricity was too dear to use for this purpose until the dynamo machine became a practical thing. Then Jablochkoff introduced his arc "candle" which was seen by all the world in Paris in 1878, and took the public imagination by its claim to do away with the intricate mechanism of the light "regulator"; but the candle, as a matter of fact, had objections of its own more serious than those of the lamps which have returned to use. The ignorant public thought that gas was about to be superseded and there was a perfect panic in shares of the gas companies: 100*l.* stock of London companies, which in January 1878 were worth 188, had fallen to 160 in January 1879, and went down to 140. That same stock in January 1892 is worth 215 and likely to retain its price.

But electric lighting, while it will not do what was expected, and will not probably supersede gas, or injure the interests of the gas companies, has a great and important field before it, which it will cultivate by degrees. Its real progress thus far has consisted in practical working out of facts well known before, and in the elaborating of details, now important, but which were not studied thoroughly until there was a prospect of their being of some value.

1208. *The electric light is not produced from electricity.* This is the rock upon which many inventors have wrecked themselves. Even scientific writers often speak of the *conversion of electricity* into light, but this is an error, as shown § 384. We do not burn electricity as we do gas or oil to produce light, and even the gas and oil are not converted into light, but into carbonic acid and water; the source of their light is their potential energy, set free as heat in the act of combustion, § 586. The process by which this heat gives light is the raising to white heat of solid particles of carbon, momentarily set free from their combined hydrogen, which is burnt first, those particles which if the flame is cooled, appear as soot. This may be shown by a Bunsen burner, giving a blue flame, with intense heat and no light, because the mixed air burns the whole of the gas: fine dust of any kind, but especially carbon, as lampblack, sprinkled into the flame, at once makes it luminous.

1209. Strange as it may sound, the process of generating light is *identical in the tallow candle, the gas flame, the electric arc,* *and the incandescent lamp;* in all of them the light proceeds from intensely heated particles of carbon, and the *efficiency* of each process depends on *the temperature to which carbon is raised.*

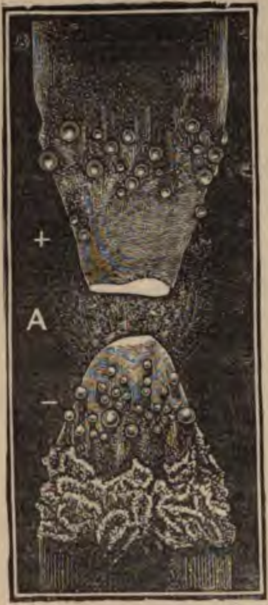
It is ENERGY *that is converted into light in all cases.* It is the *cost* of the energy and its *density* in each kind of light, which constitutes the ratio of economy and efficiency. We may even go a stage further and say that the process of developing energy is the same in all cases. In the tallow candle we have a crude gas retort in the wick, which draws the melted fat up to a point at which it is exposed to a heat at which it is vaporized, and then burnt. In the gas factory we have the same process, more perfectly carried out, and a purer gas produced. The fire of the steam boiler fulfils the same function for the electric light, and by the aid of the dynamo machine eliminates all the material residues, and delivers *pure energy* at the point of application.

1210. Here is the true distinction among the lights; with the oil and the gas, we generate the energy in presence of the waste materials of the process, and a large part of the energy has to be expended in heating and carrying away the resultant water and carbonic acid, and the residuary nitrogen of the air. These have to be equally got rid of in the electric process, but it is done at a distance; therefore we are not limited to the quantity of energy contained, potential, in the matter itself, less that necessarily lost; we can concentrate the energy itself, electricity is its vehicle, instead of combined matter, and surrenders it in the act of lowering its potential.

1211. The result is that in lighting by combustion, the "density of the energy" is limited, and in each case can only rise to the temperatures shown in the table of flames, § 1190, while, in the electric light, the only limit is the capacity of the matter in which the light is generated—the temperature to which it can be raised. This brings us to the two systems of electric lighting: by the *arc*, and by *incandescence.*

1212. THE VOLTAIC ARC.—This is the name given to what is really a constant "brush discharge." That produced by friction machines, § 112, is due to the great E M F existing between the conductors, which breaks down the resistance of the air: it is, however, a current more or less sustained, and gives a light proportioned to the energy present in it, and related (§ 114) to the matter in the space and that carried from the poles. The *arc* forms under a comparatively low E M F, which is compensated by the reduced resistance of the air, due to its being intensely heated. As a consequence, the arc cannot be developed across an open space; it is necessary for the conductors to touch so that the current passes, and then to be separated gradually. During this action the current heats the air and vaporizes a portion of the conductor, thus filling the growing interval with a gaseous conductor, and with a light proportioned to the energy transmitted to, and expended in this conductor.

FIG. 107.



1213. The appearance of the arc is shown, Fig. 107, as seen through dark glasses by aid of a lens which magnifies it. It is such an arc as is obtained with the old retort carbons, rather than with the artificial ones: the globules are caused by the silica, iron, and sulphur present in the graphite, from which the prepared carbon is purified. The + carbon is usually uppermost, and being more highly heated by the current, burns away most rapidly: particles of it are transferred, as in electrolysis, to the – carbon which forms a pointed cone, while the + carbon forms a hollow crater of intense brightness, and acts as a sort of condenser to throw a large proportion of the light downwards.

1214. *Temperature of the arc.*—The latest researches give a high value for this, and Becquerel found it 2100° centigrade; while Rossetti, after numerous experiments, gives

	× Carbon.	Arc.	– Carbon.
With 80 Bunsens	2870	3500	2400 Cent.
Maximum ..	3900	4800	3150 „

It is evident that the temperature of the carbons must be varied with their dimensions, and that their rate of combustion will also be affected; but it is stated that the temperature of the arc is independent of its *thickness* or of the current passing. On the other hand, it is lower with reduced voltage which would reduce the *length* of the arc.

The most refractory minerals fuse and volatilize in the arc, and as it dissociates most substances and reduces them to the elementary condition, it is the most powerful instrument of analysis we possess. On the large scale it becomes the "electrical furnace," § 852.

1215. *The light of the arc* is compound, consisting of the pure white light from the incandescent carbons, and the specific bright rays of the incandescent gases of the arc itself: the first of these is even whiter than sunlight, because this has lost the rays belonging to the dark lines of the solar spectrum, and much of the violet end, which is absorbed in passing through the atmosphere, thus leaving an excess of yellow in sunlight, which excess is still greater in gas and oil flames in proportion to their lower temperature. But the light of the arc consists of a faint continuous spectrum from the incandescent solid particles, and bright rays of specific gases, nitrogen and carbon, which are principally in the blue and violet: these give the steel glitter to the arc light, which is so ghastly in its effects, and unfits this light for internal domestic uses. The shorter the arc space, the whiter the light becomes.

1216. *Colours by arc light.*—A consequence of this is, that while coloured objects are brought out with great vividness, they are not seen in either natural or pleasant tints. At first, a great advantage was claimed for the electric light on this head, because blues and greens are not properly seen by gaslight, owing to the deficiency of the blue rays. But the excess of these in the arc has its own drawbacks, as all whites and most light colours are overborne, because they reflect all the rays to some extent as well as their own specific colour. This is strikingly seen when a fruiterer's shop is lighted up by arc lights; we can seen at once that the variously coloured fruits have a most unnatural and harsh appearance. This may be corrected by tinted glasses, and the incandescent lamps have not the same defect.

1217. *Penetrating power* depends upon the intrinsic brightness of a light, and the quality of the rays it emits. Intrinsic brightness is not affected by distance, that is, light is not absorbed in traversing pure space, but the atmosphere acts very differently at different times, and its absorbing power differs greatly with different kinds of lights, as the fine particles of dust and moisture take up particular rays and diffuse them, which is the cause of the blueness of the sky and of water. The short wave-lengths are most affected in this way, so that lights, rich in them as the arc light is, suffer the greatest proportional loss.

This may be seen on Westminster Bridge on misty nights: the embankment has the Jablochkoff candles on the water side, and the common gas lamps on the other side of the road; at a certain distance they become indistinguishable in spite of the great difference in their light power: a little further, and the gas-lamps may be seen while the others disappear.

Lighthouses are seriously affected by this; it is now suggested that the light should be thrown vertically so as to produce a pillar of light, visible at great distances, and more visible in foggy weather than the most powerful horizontal beam.

1218. The *resistance of the arc* has been very differently valued. Siemens has given it as about 1 ohm; W. H. Preece 1 to 3; while Ayrton and Perry, with varying battery power in Bunsen cells, give it as 12 ohms with 60 cells, 20 with 80, and 30 with 122, growing more rapidly than the resistance of the battery.

Schwendler found that with an arc of fixed length the *resistance varies inversely as the current:* this is readily comprehended when we see that increased current does not so much affect the existing arc as increase its sectional area by introducing more conducting material, so that the arc acts as an expanding pipe would with water. O. Frohlich finds that in the same arc the resistance may vary from 1 to 40 ohms according to the current passing.

1219. The *E M F in the arc* varies with its length, and according to the experiments of Professors Ayrton and Perry, as a curve corresponding to that of "length of spark" in De la Rue's experiments, § 116. They found that an arc of one-tenth of an inch requires 60 volts, increasing quickly up to a quarter inch, and after that at the rate of 54 volts per inch. The experiments of Frohlich are consistent with such a curve.

A *counter E M F* is set up by the arc, possibly similar to that noted, § 691. Its existence has been much debated, but appears to be proved, as a strong back current is said to be set up from the electrical furnaces, § 1214, after current is cut off. Some have calculated this—E M F at 39 volts,

1220. *Products of the arc.*—Mr. Wills announced the production of nitrous acid very soon after the introduction of the Jablochkoff candle, and collected 12 grains per hour from an arc lamp; there are also produced acetylene and prussic acid, chiefly at the + carbon. Professor Dewar used hollow carbons to draw off the products of the arc by suction; it does not follow therefore, that such products escape to any great extent, as they would be oxidized towards the outer surface of the arc. But the nitrous products resulting from the union of the nitrogen and oxygen of the air, must pass into the atmosphere and can always be smelt wherever arc lights are burned in inclosed spaces. They produce sore throats, and do the same or worse damage to books and goods, as that which is effected by gas. Of course there is carbonic acid also produced equivalent to the carbon consumed ; as ordinary gas contains about 1·34 grains of carbon per foot, it is evident that in the arc lamp every grain of carbon consumed corresponds to ·75 feet of gas burnt in the same time.

1221. *Applications of the arc light.*—It is best suited to exterior purposes, as for carrying on open-air work at night: it is also useful in factories, where a general illumination is required over a large area, rather than at individual points. The best mode of using it in such cases is under a curved roof or screen for a reflector, the lights themselves being suspended under the roof, with a semi-transparent reflector below them, which prevents the lights themselves from being seen, and takes up part of the direct rays, and distributes them to a distance by direct reflection from the upper surface.

The *fluctuating character* of the arc light renders it specially unfit for reading-rooms, as being injurious to the sight from the constantly changing adjustment of the eye required: and the products would be injurious to the books. In such places the incandescent lamps are the right thing.

1222. ARC LAMPS.—These are now so common, and so varied in construction, that space will permit a description only of the fundamental principles. The prime object is to keep the light uniform in quality, which it may be said is not attained in any form and probably is not to be attained ; all jump occasionally, and it would appear that some fluctuation is inevitable: the causes are inherent in the process of burning away the carbon rods, and the irregularities of structure in the rods: hence the distance apart continually changes, and the object of the mechanism is to compensate as steadily as possible for this change: but this can only be brought about by the effects of the change, by variation in the current passing, with a resulting variation of the light given.

1223. There are two distinct systems in use. (1) *Gravitation* or spring pressure, may be used to bring the carbons together, and then the apparatus separates them so as to fulfil the conditions of § 1212: then the weight continues to feed, controlled by this separating action set up by the magnetism developed by the current which feeds the lamp. (2) The differential influence of two magnetic actions of the current may be utilized to maintain a uniform resistance in the arc, or a fixed rate of current, or preferably a fixed difference of potentials, which being independent of the currents, enables several lamps to be worked independently on one circuit.

1224. In the most elementary form of regulator the upper carbon slides in a metal clip by its own weight; one side of the clip is connected to the armature of an electro-magnet, which causes a pressure increasing with current, so that when the current is reduced by the growing resistance of the lengthening arc space, the pressure diminishes, and the carbon slides down, till the growing current again stops its motion. Similar actions with more delicate automatic controlling movements are utilized in various useful lamps.

1225. The *differential* principle can be explained by the Siemens lamps, used in lighthouses. The carrier bar is actuated by a long iron core which enters into two solenoids, so that its position is regulated by the difference in the attractions these exert. One consists of a coil of stout wire carrying the current which gives the light, and its action separates the carbons. The other is a shunt circuit of high resistance, and tends to draw the carbons together. The two actions balance when the defined difference of potential exists in the arc. If the arc is too wide, the ratios alter; more current passes the shunt coil and it allows the carbons to approach.

1226. *Semi-incandescent arc lamps* were devised, in which the arc was made to heat large masses of carbon, moving so as to expose fresh surfaces, as is done in the lime-light, or blocks of resisting substances, lime, magnesia, &c., but they have not stood the test of practical use.

1227. JABLOCHKOFF CANDLE.—This, though a very imperfect light, still remains in use for some purposes, on account of its simplicity. At any rate it calls for some attention on account of the part it played in bringing electric lighting to life, § 1207. It was devised to do away with the necessity of regulating the arc by mechanism. It effects this by adjusting the distance of the carbons permanently, side by side, using alternating currents to insure equal consumption in both. The carbons are mounted in brass tubes, by which the contact is made, and separated by a layer of plaster of Paris, and at the lower end by a cement which surrounds the carbons and tubes and binds the whole together. A strip of plumbago and gum joins the upper ends of the carbons, and enables the current to pass and form the arc; but if this is once extinguished there are no means of re-lighting the candle. The plaster of Paris becomes heated, and is then a partial conductor, carrying portion of the current, becoming vividly luminous; it, however, produces the intermittent rosy tinge which frequently flashes into the light. As the candles burn only 1½ hour, a lamp is used, which contains four candles, with wires and a commutator at the foot of the lamp to throw the current into any desired one of the candles.

The light is more unsteady than that of any inferior arc lamp; and the light generated for the energy supplied is much below that of any good one. Count du Moncel placed a candle and Serrin lamp on two similar circuits of a machine, and found that the lamp gave three times the light of a candle. They give about 450 candles in their best direction, the horizontal line, which the opal globes reduce to 172, and to about 90 on the ground. Faintly ground globes are now used in this and other lights to diminish this loss of light, with the disadvantage that the glare is so great as to dazzle the eye.

A number of modified forms were devised to take a share of the temporary success of the "candle," but they have all died off.

1228. CARBONS.—At first the charcoal of wood was employed but was displaced by the graphitic deposit of gas carbon, cut into square rods: but this not only contains sulphur, iron, and silica, but is of very irregular texture, and traversed with fissures; these result in great variation of the light, and artificial carbons alone are now used. These are produced from various forms of carbon, and different makers employ different processes of purifying the carbon and making it up. Some use the retort carbon finely powdered, and boiled with alkalies and acids to remove the impurities; others employ lampblack: the agglomerating materials are gum, starch, sugar, and pitch. The materials are worked into a tough paste, pressed into rods by the hydraulic process, gradually dried in moulds, or so arranged as to keep them straight, then slowly heated up to a red heat, in coke powder contained in retorts, to drive off everything that can be vaporized. The rods are then soaked in strong syrup, or in dissolved pitch, and again dried and carbonized; the process is repeated till all porosities are filled up and an extremely dense substance is produced, having a metallic ring and a fracture like hard steel.

1229. The process of heating the carbons in a hydro-carbon vapour, called "flashing," first employed by Sawyer and Mann, and used by makers of incandescent lamps, § 1250, is employed also for arc carbons, which can be packed in a suitable retort and heated to incandescence while a stream of vapour of gas-tar is driven through the retort; this process is in fact identical with that which produces the gas carbon itself, only conducted under conditions to control and facilitate the deposit.

1230. The presence of various salts affects the light, thus, salts of sodium tend to increase the yellow rays, and are said to lengthen the arc and diminish the hissing sounds produced; borax also tends to reduce the consumption by fusing on the surface and diminishing the access of oxygen; but it appears doubtful whether there is advantage derived from any additions except the thin coating of copper which is employed in some cases to lower the resistance.

1231. *Different makes* of carbon consume at different rates with the same current and light, and it would appear that those based upon uniform materials give best results: that is to say, the carbon is a lampblack derived from burning pitch, and the cementing material the same pitch dissolved in naphtha.

The *consumption of carbon* is about twice as much at the + as at the – conductor, and the total appears to be about grain ·06 per candle of light per hour in the Jablochkoff system, and from ·1 to ·05 in the arc lamps, diminishing as the power of the lamp increases.

The most complete examination of the behaviour and duration of carbons will be found in a paper read by Mr. Louis Marks to the American Institution of Electrical Engineers, 21st May, 1890, and contained in the 'Electrician,' vol. 25, p. 154.

1232. INCANDESCENT OR GLOW LIGHT.—The fact that light could be produced by the electric current passing through highly infusible materials was known early in this century. Platinum, iridium, and carbon were all examined, and in 1845 King patented lamps of carbon in vacuo, while De Changy made successful attempts of the same nature in 1858. Therefore recent progress relates not to principles, but to details and the most effective mode of giving practical effect to the principles.

The generation of heat by the current is explained § 387, and that of light by this heat in the early part of this chapter, but it is necessary now to examine some of the facts more closely.

1233. *Atomic or molecular heat.*—In § 17 it is mentioned that heat acts upon matter according to the atomic weights, and not according to the weight or mass merely: but many facts indicate that it is not really the atomic weight, but the *molecular* weight that we ought to consider, for the same substance in the elementary state may have different relations to heat; this is particularly the case with carbon in its several forms: this fact is strikingly exemplified by many instances now known, in which a substance undergoes some unknown change at a particular temperature, by which its properties are altered; iron undergoes such a change in cooling from a great heat, and gold gives a striking illustration of such a change. When melted and super-heated, it will cool gradually and quietly till, at a certain stage it suddenly heats spontaneously and glows vividly, after which it goes on cooling quietly.

1234. This phenomenon is called *recalescence*, and in the case of iron accompanied with changes of magnetic and electric properties which prove these to be functions of material state or structure, § 1366. The *critical* points, as they are called, probably correspond to a new molecular arrangement of the atoms, to a passage from one allotropic state to another, in which a different quantity of energy is combined with the atoms, and the sudden heating is due to the potential or latent energy of one form giving up the excess of that needed for the other form: in all likelihood the number of atoms built up into one molecule is altered at this instant, with other changes of physical property, as in the case of ozone O_3 and oxygen O_2 described, § 672. It appears highly probable that such a change as occurs under these circumstances may be connected with that variation of chemical affinities by which gold, for instance, is univalent in aurous salts as the cyanide, and trivalent in auric salts as thechloride, and so generally with those metals which form two or more sets of salts of differing valencies.

1235. The result is that the same quantity of heat produces different temperatures in equal weights of the same substance; but, subject to modifications indicated § 672, a fixed quantity of heat will raise an equal number of molecules of different substances, in the same physical state, to the same temperature.

The atomic heat is the product of the atomic weight and specific heat, § 388, so that we have

$$\begin{array}{ll} \text{Platinum} & 197 \times {\cdot}0355 = 6{\cdot}99 \\ \text{Graphite} & 12 \times 2018 = 2{\cdot}42 \end{array}$$

1236. We have, however, chemical evidence that graphite is essentially different from *carbon*, of which we use the atomic weight 12; it is allotropic carbon, and if we reckon the molecule of platinum as 2 atoms, and that of graphite as 5 atoms, we should have nearly equal molecular heats, but this is a mere hypothesis at present, and these figures are given to show the variety of actions involved in the production of light, awaiting further knowledge for their application.

1237. *Atomic or molecular volume.*—As different substances have different molecular weights, and also different specific gravities, it is evident that in a conducting wire, which, § 537, is primarily a *volume* or defined space, we may have very different numbers of molecules taking part in the action, and therefore different relations to heat; these relations, like resistance, vary also with temperature, which alters volume differently in different substances.

$$\frac{\text{at. wt.}}{\text{sp. gr.}} = \text{at. vol.}\quad \text{Platinum}\left\{\frac{197\cdot}{22\cdot1} = 8\cdot91.\right. \quad \text{Graphite}\left\{\frac{12\cdot}{1\cdot06} = 11\cdot4\right.$$

Now if we multiply together these figures of atomic heat and atomic volume we get for platinum 59·3, and for carbon 25·6, as the comparative temperatures to which equal heats might raise wires of the same diameter.

1238. *Specific resistance*, p. 273, Col. III., and that modified by the variation due to temperature, would have to be taken into account in considering the effect of equal currents, and we have not as yet sufficient facts to make it worth while going further than to thus indicate a course of probably interesting research.

1239. *Radiation capacity.*—Not only has each gas its own spectral lines, § 1172, but each solid substance, while generating all the rays corresponding to its temperature, § 1186, has a capacity for generating or emitting specific rays in greatest abundance; thus, if a piece of white earthenware with a dark pattern upon it be heated in a furnace, when seen in the dark by its own light, the dark pattern will appear the brightest, that is to say, it will emit the light-rays of the spectrum more freely than the white ground, though both are at the same temperature. If a platinum wire be partly polished and part roughened, the rough part will be brightest when heated: also, a piece of glass and of iron being heated in a furnace, to the same heat, the iron will be bright, while the glass will give little light; on the other hand the glass would be found to emit more of the dark rays than the iron. Carbon has this property in a high degree, and it appears probable that if all other conditions were equalized, carbon would emit more light than platinum.

1240. GLOW LAMPS.—The following extracts from a lecture given in Newcastle, by Mr. Swan, 20th October, 1880, will give the most interesting account of the origin of the incandescent lamp. After describing Mr. Edison's experiments with platinum, he says:—

> "It had appeared to me for many years, that if ever electric light was to become generally useful, it would most probably be by the incandescence of carbon. I had long before the time to which I am referring rendered this idea practicable. As a matter of history, I will describe an experiment which I tried about twenty years ago.
>
> "I had a number of pieces of card and paper, of various forms and sizes, buried in charcoal in a crucible. This crucible I sent to be heated white hot in one of the pottery kilns belonging to Mr. Wallace of Forth Banks. . . . My carbon was in the form of an arch, about one inch high and a quarter of an inch wide; the ends of the arch were held in small clamps with square blocks of carbon. The

air-pump having been worked, I had the pleasure of seeing that with the battery of 40 or 50 cells, my carbonized paper arch became red hot, and that nothing more was wanted than a still stronger current to make it give out a brilliant light.

"That, I confidently believe, was the very first instance in which carbonized paper was ever used in the construction of an incandescent electric lamp. I am now speaking of twenty years ago, and at that time the voltaic battery was the cheapest source of electricity known, and the means of producing high vacua were very much less perfect than they are now. I laid my electric light experiments aside till about three years ago, when two things concurred to lead me to pursue the subject afresh.

"The discovery of the dynamo-machine had entirely altered the position of the question of electric lighting. The Sprengel air-pump too had been invented, giving much higher vacua than the old form of air-pump. Mr. Crookes' radiometer experiments had shown us what a really high vacuum was, and how to produce it.

"I had the good fortune to make Mr. Stearn's acquaintance (who had acquired such a knowlege of the Sprengel pump as was only equalled by that of Mr. Crookes himself), and that was one of the determining causes of my second attempt to solve the problem of electric lighting by the incandescence of carbon.

"In October 1877, I sent to Mr. Stearn a number of carbons made from carbonized cardboard, with the request that he would get them mounted for me in glass globes, and then exhaust the air as completely as possible.

"In order to produce a good vacuum it was found necessary to heat the carbon to a very high degree *during the process of exhaustion*, so as to expel the air occluded by the carbon in the cold state. In order to make a good contact between the carbon and the clips supporting it, the ends of the carbons were thickened, and in some of the early experiments, electrotyping and hard soldering of the ends of the carbons to platinum was resorted to."

1241. In the latter part of 1878 Mr. Edison turned his attention to incandescent lighting, and it would appear that the actual invention, the announcement of which produced the panic referred to, § 1207, was really one of which nothing has since been heard, viz. a semi-conducting incandescent material compounded of infusible earths and carbon or metals. I had myself patented a nearly identical idea within eight days of the date of Mr. Edison's patent, and had tested and found it worthless, while the scare was in full vigour; and I may say that the idea was suggested to me by the vivid light shown by Jablochkoff at the 1878 Exhibition, derived from a thin strip of plaster of Paris made incandescent by an induction coil.

1242. Mr. Edison then took up platinum and made a very good lamp, based upon his re-discovery of the effect of gradual repeated heating in rendering platinum more coherent and infusible; but even this would not stand working, and then his admirable perseverance in the endeavour to accomplish what he had promised to do, led him to try carbon, and in his patent of the 10th November, 1879, he speaks of using "carbon wires," and says he has discovered that even a cotton thread properly carbonized is absolutely stable at very high temperatures in a sealed bulb exhausted to one-millionth of an atmosphere. His inexhaustible experimental energy led him to examine almost every imaginable carbon-producing substance, and after Bristol board punched out, he ultimately settled upon bamboo shaped into suitable form.

1243. As to the order of discovery, Mr. Swan went on to say:—

> "In an article which appeared in the February number of *Scribner's Magazine*, authenticated by a letter from Mr. Edison in the same publication, it is stated that Mr. Edison was the first to use carbonized paper; that is incorrect. And this also occurs after a description of Sprengel's pump used in exhausting these lamps: 'Mr. Edison's use of carbon in such a vacuum is entirely new.' Now, I daresay there are many here who will remember this little lamp, which I showed here two years ago in action. This lamp has exactly the same simplicity as my present lamp, being composed entirely of three substances, viz. glass, platinum and carbon, and it was exhausted in precisely the same manner, and to the same degree, as that which Mr. Upton—no doubt in good faith, but still in error—speaks of as '*entirely new*,' I do not mention these things in any way to disparage Mr. Edison, for no one can esteem more highly his inventive genius than I do. I merely state these facts because I think it is right to do so in my own interest, and in the interests of true history."

1244. As a matter of true history, neither Mr. Swan nor Mr. Edison have any claim (though this was set up and promised a fruitful harvest to the lawyers) to the use of carbon and vacuum, singly or combined. They used a finer *thread* or *wire* of carbon than previous experimenters, or at least than others were publicly acquainted with, but this gave no right to material or size, for others had only been limited in this matter by the difficulty of producing very thin carbon rods: every one had sought to use as perfect vacuum as possible, and there was no discovery in using the improved vacua open to every one for any purpose. The real improvements of both claimants consist in the modes of obtaining a "carbon wire," and in the details of the construction of the lamp itself.

The *incandescence of carbon in vacuum* was patented by King in 1845, and invented by Starr, an American, associated with King in electric lighting: they used the best vacuum then attainable, that produced in a barometer tube, and Mr. Mattieu Williams, who was working with them, says, "we had no difficulty in obtaining a splendid and perfectly steady light. We used platinum, and alloys of platinum and iridium, and then tried a multitude of forms of carbon, including burnt cane."

M. Jobard in 1838 published the idea of using a small carbon as a conductor of current in a vacuum; and M. de Changy made effective lamps of this kind which were submitted to the Academy of Brussels in 1858.

1245. Patent Law and Science.—We have had numerous suits over the progress of electric lighting, the cost of which the public has to pay in the long run, which have set up most unfortunate precedents. Most of these actions have not really been about real *inventions* at all. The man who makes a real discovery and works it out is a benefactor who ought to be rewarded: but we cannot say that of a man who makes only the first grasp at a *piece of common knowledge.* If the real foundation of a claim to a patent is the giving of something to the public which it might not otherwise obtain (and this is the theoretically legal and reasonable foundation) there ought to be no patent for merely applying a well known fact to a purpose, self obvious as soon as the purpose is worth accomplishing.

Every one knows that currents will work apparatus in series or in arc, and each has its advantages: yet most serious claims are patented to the right of distributing upon one or other of these principles. Claims of this order are even based upon mere accidental expressions made without any clear knowledge at the time, but with a meaning read into them afterwards. Let lawyers say what they will, this is a wrong on the public.

Perhaps the best definition of a just patent is that of Justice Giles of America in the Singer machine case: "Patents are not monopolies, because a monopoly is that which segregates what was common before, and gives it to one person or class for use or profit. A patent is that which brings out from the realm of mind something that never existed before, and gives it to the country."

1246. It is remarkable that the two leading inventors of the carbon lamp, Swan and Edison, each claim a *definite principle* in producing the carbon wire. Mr. Swan took an organized structure, crotchet cotton, and *destroys that structure* by acting on it with acid, so as to reduce the cotton fibres to a gummy substance before carbonizing. Mr. Edison used the bamboo strip *because it has a definite structural form.* It may be that the presence of silica plays an important part in the Edison lamp, but it is very evident that neither of these principles can have any importance, because makers of lamps pay no attention to them, but Mr. Swan's process is most generally used, and Mr. Edison's name of "filament" for the conductor proved of great importance legally.

Other names must not be overlooked, and Mr. St. George Lane Fox ranks nearly parallel to Swan and Edison in the introduction of incandescent lighting, though for some reason he fell out of sight. There is, however, no pretension in this work to examine questions of priority or merit, except incidentally and in the course of description.

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1247. The differences in the various lamps consist in details, some of which require separate consideration.

Form of carbon wire.—The *Edison* is a tall arch; the *Swan* is a similar arch, of which the upper part makes a spiral of one turn of half an inch diameter. The *Maxim* is a longer carbon folded up in the form of M. All this is not a mere matter of form; they act very differently upon the eye: when the "wire" is incandescent it appears to be very greatly increased in size; this is an optical effect in the eye itself, a result of *irradiation.* The result is that a grating of wires near each other appears to blend in one mass of light which is less distressing to the sight than an equal quantity of light issuing from one distinct wire; thus a Maxim light is more easy to the eye than an Edison of equal power, and the Swan is intermediate.

1248. *Dimensions of carbon.*—These are governed by the same principles as the heating of wires, § 387. Therefore the light given is proportional to the *length* of equal wires, subject to the greater loss of heat in short wires by the more rapid cooling through the connections: for this reason incandescent light is readily subdivisible with little loss, while arc lighting suffers a loss at least as the square of the division.

The smaller the wire the greater the economy, because of the facility of generating high temperature: but this reduction is limited by the capacity of the material to endure the temperature without speedy destruction.

The best *diameter* is still a subject of experiment, and will yet be influenced by improvement in the structure of the carbon itself. The Swan lamp carbon is about 0·25 mm. in diameter, and the Siemens 25 candle is 0·27 mm., both of circular section, whilst the Edison 16 candle carbon is of oblong section, with sides 0·1 and 0·2 mm.

Lamps are also made of much larger sections, such as Bernstein's low resistance lamp, formed of a hollow cylinder of carbon, so as to obtain large radiating surface with small quantity of material, using larger current and lower voltage than are found to give the best results by other makers.

1249. *Different materials* are employed to produce the "filament." The carbon threads or wires could not have been imagined a few years ago. It is true we are acquainted with carbon in different forms, as the intensely hard transparent diamond, the friable charcoal, and the crystalline graphite; but none of these could be conceived as forming a slender filament of any strength or durability. But the "wire" of the incandescent lamp as now produced is really a *wire*; it is strong, tough, and flexible to a degree comparable with metals, and therefore will bear the inevitable shocks of transport. Its appearance also is that of a grey granular metal, not unlike coarse steel in fracture.

The Swan and Edison carbons of the early forms are mentioned § 1246: the one was made from crotchet cotton parchentized by acids, and the other from selected bamboo strips. *Lane Fox* used the vegetable fibre employed for brooms, and others have tried every conceivable fibre: some assert that a vegetable fibre covered with animal fibre such as silk, is the best, and many use cellulose dissolved in various ways and brought to a soft paste which can be forced through a suitable hole in a cylinder, as lead wire is made, rolled, and otherwise treated.

1250. The material is put into the desired form, then carbonized with various treatments, attached to two platinum wires sealed into glass and enclosed in the bulb.

The *flashing* process consists of strongly heating the carbon by passing current through it in a bulb filled either with a hydro-carbon vapour, or in some cases with a liquid or solid paraffin: the result, as in § 1229, is to deposit an exceedingly dense coating of graphite, while the action can be controlled so as to obtain a carbon of just the resistance desired to fit each lamp for its special work.

When the controlling or "master" patents expire in 1893 no doubt there will be a crowd of improvements brought forward as regards both quality and cost of the lamps.

1251. EFFICIENCY *of Incandescent Lamps.*—A clear distinction should be drawn between the *efficiency* of different lamps, and the *cost* of the light from them. The *efficiency* relates only to the *quantity of energy consumed per candle-power produced.* The *cost* depends upon this multiplied by the *cost of the energy* as delivered to the source of light. Efficiency is commonly expressed by the *Watts* expended per candle-power or inversely by the "candles" developed per horse-power, which should be electrical horse-power, § 1111, not that of the engine.

1252. This expression of *light per H.P.* is useful as a striking illustration of the different light-producing effects of combustion and electricity. In § 1107 it has been shown that 21 feet of gas will develop 1 H.P. in a gas engine: this gas at 16 candle-power will represent 67·2 candle-hours of light. This engine driving a dynamo would work 12 lamps of 16 candles or give, say, 200 candles of light. Therefore *the light-giving efficiency of the electric system is threefold that of combustion in this case,* which is a fair comparison of similar lights. An arc lamp might give 1200 candles, or eighteenfold efficiency, but this would not be a reasonable comparison.

But if we compare *cost* the result would be very different: the 21 feet of gas would cost only its price, while to treble its yield of light by electricity would need the extra expense of the engine and dynamo with the necessary labour.

1253. *The energy expended per candle-power* in the light itself is the proper test of efficiency of the light source, and it may be well to use gas as a starting point. On the data of § 1107, 5 cubic feet of gas, giving 16 candle-power for one hour, represents lb. ·15 and energy in foot-lbs. 2,550,000: this is foot-lbs. 159,375 per candle hour, or 60 watts. But this high figure is not really comparable with those of the electric light, because the latter represent the *nett* energy expended in heating the carbon, the various necessary wastes having taken place in the fires and engines, while in the case of gas we have to deal with the *gross* energy and effect these wastes in the flame itself, § 1210.

In the ordinary fish-tail burners the gas gives on the average little more than 10 candles, but that is a defect not of the gas but of the burners, and for which the consumers have to blame themselves as also for not providing proper ventilation.

The relative cost, however, depends on the cost of energy from different sources, § 1111. That of 5 feet of gas at 3*s.* is in pence ·180 for 16 candle hours. If we take 4 watts as the practical equivalent of the incandescent light, this is 64 watts for a 16 candle lamp and this at 6*d.* per unit is pence ·384 or double the cost of gas, and this is found to be practically the relative costs.

1254. *The watts per candle* needed to maintain the light is the usual expression of efficiency and cost with the incandescent electric light. This has been gradually lowered by improved make. The following table showing the value of different lamps tried, will give useful information together with that in § 1264. They are not very recent, but it is not easy to obtain recent trustworthy data.

Siemen's Lamps.	New.			Earlier.			Edison A Lamp
	II.	IV.	VI.	II.	IV.	VI.	
Normal candles	12	16	26	12	16	26	16
Volts	100	100	100	102·1	101·4	101·7	100·4
Amperes	·41	55·	80·	·50	·72	1·15	71
Ohms (hot) ..	244	182	125·	204	141	88	141
Volt-amperes ..	40·05	55	80	51·5	72·6	116·9	71·5
Watts per candle	3·34	3·44	3·08	4·29	4·54	4·49	4·47
Candles per elec. H.P.	210	206	221	165	157	153	159

Statements are often made about lamps working at 2·5 watts, and as mere facts they may be true. But directly a lamp is worked beyond its proper limit its efficiency drops and its light emission lowers. Trustworthy authorities say that the average requirement over the working life of a lamp is about 4·5 watts per candle. It is not well that consumers should expect more than they are likely to obtain.

1255. *Heat effect of lights.*—The incandescent lamps generate much less heat for equal light than any combustion process: in fact the *ratio* would be that of the relative energies in the lights, but for the amount carried off *potential* in carbonic acid and water vapour: the actual result, by experiment, is that the incandescent lamp gives about one-tenth the heat of an equal gas-light, with absolute freedom from noxious products; this is the real advantage of the incandescent light over gas, as the use of even high illuminating power has no effect upon the health, nor upon books, pictures, &c.

1256. These are matters of great importance in lighting *public assemblies;* the presence of moisture and carbonic acid affects the sound-transmitting power of the air, and the row of foot-lights across the front of a stage sends up a screen of these gases: it is found that these affect the transmission of music, which is therefore more effective when a row of incandescent burners replaces the usual gas-jets.

Musical instruments keep tune better, and this applies specially to organs which are deranged when there are layers of air of different temperatures affecting their different sets of pipes.

1257. *Duration of the Lamps.*—This has been greatly increased as the manufacture has improved. At first they failed very quickly and gave way under any undue current. Not only has the quality of the carbon wire been improved and its tendency to vaporize reduced, but the proper limit for each type of lamp is better known. The "life of the lamp" is now averaged and even guaranteed at 1000 hours, and there are instances of their working for 6000 hours. But this applies to cases where they receive care. Private houses where they take their chance of management will probably find their constitutions weaker, and their users should see to it that the fittings, fuzes, &c., are so arranged that they cannot be subjected to over-strain.

1258. The *giving way of the carbon* is attended with some curious effects: they commonly break near to the junction with the platinum, which may be due to a mechanical stress consequent on expansion and contraction, or at some point which, offering a higher resistance, gets unduly heated: this latter should not happen, as the process of flashing, § 1250, automatically remedies trifling irregularities, as the greater heat there reduces the carbon more at the required spot.

1259. The *Edison effect* throws light upon the causes of injury: if a metallic plate, isolated from the carbon, is supported within the arch by a wire with a third terminal, a current passes from the + side of the carbon arch to this plate, but not in the reverse direction. This, with many other facts, shows that there is really a *directive* agency in the current, and that natural facts correspond to the convention that current is reckoned from + to −. We find similar differences in the carbons of the arc, and in the brush and spark discharge.

1260. The *dissipation of the carbon* appears not to be a vaporization by heat, or distillation, but an impulsive action similar to that which produces so many beautiful effects in Crooke's vacuum tubes, that action which is called the "bombardment of the molecules"; the surface of the carbon, when examined under the microscope, appears to have been subjected to stresses tending to make it "bristly" and to have torn out the less coherent portions.

1261. The *arch throws a shadow* of itself, a light line in the dark carbon film where the line of the carbon has itself received the projected particles and prevented them from reaching the glass. *Copper* is in like manner thrown off from the junction of carbon and platinum when this is coppered. The effect upon light of the carbon deposit is shown, § 1204.

1262. As this action occurs from the + side, fracture of the carbon is most frequent near the + terminal: therefore it would be well to reverse either the lamps or the whole circuit at intervals. With intermittent currents this does not apply, but they introduce their own causes of injury. One of these is the circumstance that while the supply, the light, &c., are based on the "effective" current and voltage, § 431, the actual values, the crest of the wave rises to about one-third above this, that is if the *maximum* is 10, the *effective* is 6·4, and this not only needs more insulation than an equal steady current, but it puts greater stresses on the carbon.

Experience will soon decide whether the life of the lamps is on the whole greater with constant or alternating supply; but at present it is not really known.

1263. Ratios of Light to Current and Energy.—Light is a function of temperature, but does not increase in the same ratio: temperature is a function of energy subject to specific molecular properties of matter, and energy is as the square of the current, all other things remaining unchanged. From a comparison of the results of many observers it appears that the *light* increases as the sixth power of the current, C^6. If we follow out the real meaning of this, we see that it means the cube of the energy expended $(C^2)^3$, or rather it would do so if the resistance was unaltered: a stage further brings us to this result, that the temperature varies as the cube of the energy, and thus the light is as the temperature, which appears to be untrue, § 1190. This may also be expressed by the cube of the Watt's expended.

One experimenter finds that $(C - C_1)^4$ gives the best expression for the luminous power, C being the actual current, and C_1 that at which the lamp begins to show faint red. Some experiments by M. Felix Lucas illustrate this. He used thin arc carbons in a vacuum: as the heat rose the light grew rapidly to over 300 carcels and then more slowly till at 4500° C. the light was 413 carcels. But raising temperature to 4700° C. only gave 420 carcels, and a rise to 5000° C. brought it down again to 413.

1264. *Such formulæ cannot possibly be true:* they are mere empirical expressions for the actions within a limited range, within which they are useful, but beyond which they mislead. It is evident that the true law must be a falling curve analogous to those of magnetism, and that this curve will be different in metals and in carbon because of the reverse order of resistance variation. The table, though obsolete as to actual lamps, illustrates that fact, as the older Cruto lamp was a platinum wire upon which carbon had been deposited by flashing, § 1229. It would repay the student to work out the corresponding curves which explain § 1191–3.

Ratio of Light to Current and Work.

Swan.—46 Volt Lamps.					Cruto.—No. 2 Lamp.				
Candle-power.	E. Volts.	C. Ampères	Watts per candle.	R. Ohms.	Candle-power.	E Volts.	C. Ampères.	Watts per candle.	R. Ohms.
·5	26.	·73	38·	35.6	—	5·69	·160	—	35·6
·97	29·	·83	24·9	34·9	—	11·34	·294	—	38·5
1·6	30·3	·87	16·4	34·8	1·2	22·17	·539	9·9	41·1
3·39	34·8	1·01	10·5	34·5	2·3	25·52	·611	6·8	41·7
5·69	37·1	1·10	7·2	33·7	3·3	27·33	·644	5·3	42·5
8·40	39·9	1·19	5·7	33·6	4·4	29·05	·681	4·5	42·7
10·7	41·2	1·23	5·8	33·5	5·85	30·99	·710	3·8	43·5
15·2	43·8	1·31	3·8	33·4	7·2	32·29	·742	3·3	43·6
24·1	47·6	1·44	2·8	33·1	9·2	34·01	·772	2·9	44·0
33·6	51·2	1·56	2·4	32·8	11·8	35·78	·801	2·4	44·7
48·0	53·4	1·64	1·8	32·5	15·7	37·47	·817	2·0	45·8
56·0	55·0	1·72	1·7	32·0					
62·5	55·8	1·76	1·6	31·7					

1265. A constant is necessary for each kind of lamp, because the quality and surface of the carbon modify its emissive power, § 1239, and consequently the temperature to which a given current will raise it.

The *vacuum* is an important element of that constant, because the relative cooling, that is waste of heat of two lamps exactly similar in other respects may differ greatly on this account, § 560. Slight loss of vacuum is the cause of failure with many lamps, owing to leakage where the platinum wires cross the glass.

1266. THE COST OF ELECTRIC LIGHTING.—At first the most erroneous statements were made as to this, which led to extravagant expectations on the part of the public, and stimulated unwise investments which resulted in heavy losses. The basis of the error was the comparing together things having no relation: arc lamps giving 2000 candles light with gas-lights of 10 or 16 candles power, § 1252.

It would be waste of time to consider the cost of *arc lighting*, as it varies with each case: the only useful information would be a statement of what has been attained under several conditions, and this would be out of place in this work.

1267. Statements commonly made as to the *incandescent* lights are also misleading when different lamps are compared, because while all become economical the higher they are forced, each one has its proper limit at which it will do best work, while working uninjured; a comparison of mere light per horse-power, or watts per candle is, therefore, worthless, except at that limit, because beyond that limit the lamp will be speedily destroyed. Users should learn exactly the voltage for which their lamps are meant to work, and carefully avoid using anything higher: they should not be led away by any statements as to "efficiency," § 1251. There is really little difference among lamps in this respect, while there may be much as to practical cost.

1268. This can be put into a simple formula which will express the law of *true economy*, or the "figure of merit" of lamps.

$$\frac{\text{Cost of lamp} + \text{Cost of current} \times \text{time.}}{\text{Average candle-power} \times \text{life of lamp.}}$$

"Time" and "life of lamp" would be the same number of hours.

1269. The old saying "that nothing is so false as facts, except figures," applies very thoroughly to this subject. Nothing is easier than to take the facts of a special case—true facts, and by applying them to other cases get false figures. Thus advocates of electric lighting frequently assert that it is as cheap or cheaper than gas. This is false, and yet it may be true.

It is pretty safe to say that the cost of incandescent light is on the average, in England, *twice that of gas, and likely to remain so.* But if we take other points into account, damage to goods, and so on, § 1255, it may be much *cheaper than gas;* only let people understand what is meant by cheapness. Also figures obtained from private generation ought not to be applied to "supply" current.

1270. This is one of those matters in which "a little knowledge is a dangerous thing," § 1. In private installations an important element in the question of cost is the time during which the light is to be employed: the interest on capital outlay, &c., and often even wages for attendance will be the same for 500 hours a year as for 2000, while in many cases of factories these would cost little more than the extra fuel consumed, and the value of the dynamo and fittings. This does not count in the case of gas supplied by a meter; nor would it in the corresponding case of distributed electricity; and the only true way to estimate cost is to consider the actual conditions of each case and apply to it the considerations of §§ 1252–4 and § 1267.

1271. FITTINGS.—It is impossible to describe these: they are the subjects of many inventions, or at all events, patents; but they are really adaptations, to the specific purpose, of well-known means, either already described or obvious to any one skilled in the subject: they are merely forms of connections, commutators, &c., modelled on the ordinary gas fittings, while the supports, electroliers, &c., are rather matters of art than of science, and however suitable to a work on electric lighting, would be out of place here.

CHAPTER XIV.

MISCELLANEOUS.

1272. THE ELECTRIC TELEGRAPH.—This subject it is not necessary to go into at all, as it is cursorily sketched in every work on electricity, and useful knowledge can be given only by the technical works. It is essentially an application of principles fully explained throughout this work, and resolves itself into three distinct systems.

(1) *Indicatory*, such as that of the needle instruments, which are to all intents vertical galvanometers, § 354.

(2) *Recording* or *Mechanical.*—Such are the Morse and the printing systems, as well as those alphabetical instruments which do not record, but make a temporary indication. All these are actuated by electro-magnets working or releasing clockwork. Some of these also work by sound, the taps of the electro-magnet answering to the contacts made.

(3) *Chemical.*—These work by electrolysis, producing coloured marks when current is passed to the electrodes, one of which is a revolving cylinder, the other a point, a sheet of paper moistened with the electrolyte being interposed and drawn between the cylinder and the style.

The telegraph system is, therefore, the effecting of common electric actions at a distance, and is wholly a matter of resistances, and instruments fitted to work with small currents.

1273. *Duplex Telegraphy.*—This, the causing two messages to be transmitted by one wire in opposite directions at the same time, has only been practically effected within a recent period, though the principles involved were known long before. It depends upon a very careful balancing of resistances: the currents do not pass each other at all, but if signals are sent simultaneously the effect is that the receiving instruments are really worked by the batteries of their own station, not by that of the sending station.

The instrument is essentially an electro-magnet wound with two wires like a differential galvanometer, and acting upon the same principles. In one circuit is the line wire, and in the other a resistance equal to that of the line. Currents sent into this instrument from its own end will therefore not actuate it, as they divide into two equal parts; but a current entering by the line will actuate it, for (1) the station itself is *not* sending a current; then the line current passes through one circuit to the junction and back through the other, through a double resistance, but with double force, and so works the instruments in the usual way. (2) The receiving station is also sending; then according to the direction of the currents, one of the two circuits contains an additional or an opposing E M F, and thus an extra portion of the current enters one of the circuits and actuates its own instrument. The two instruments at opposite ends of the line being alike, and the resistances properly balanced, the operator at A station always sends his signals into his own instrument, but these do not affect it unless B is also sending signals into it, and therefore each operator only sees upon his instrument the result of the signals transmitted by the other operator, although they may be actually produced by his own battery set in motion by himself.

1274. In submarine cables, there is, besides the line-resistance, the vanishing resistance due to "impedance," and to work on the duplex system a similar condition must be produced in the secondary or home circuit. This is effected by using, with the resistance equal to that of the line, condensers equivalent to the charge the cable is capable of taking up.

1275. *Quadruplex* telegraphy is effected on similar principles by using E M F's and instruments actuated by only one of the currents transmitted; a low force being unable to pass through a very high resistance instrument, while a small current under high force, which will actuate this, is without effect upon an instrument arranged to work with a larger current.

1276. AUTOMATIC TRANSMITTERS.—There have been many forms patented, but all are modifications of that first introduced by Bain to work his chemical receiving instrument. In principle the transmitter and receiver are the same. In each a revolving drum or cylinder rotates under a metallic style: in the receiver these are separated and yet electrically connected by a paper moistened with an electrolyte which permits current to pass, and by the change of colour produced, records the time during which current passes. In the transmitter a strip or sheet of paper is interposed, which is perforated to permit the points to touch the cylinder, and allow the current to pass at the proper times: thus the marks on the receiving paper correspond to the perforations in the transmitting paper. But by the same means any kind of receiving instrument can be worked, as all transmitting instruments depend upon the making and breaking contact in one or more circuits for different graduated intervals, and the paper can be arranged to effect this mechanically. In other cases a sheet of metal is used, either as a cylinder or in a flat form, and is written upon with an insulating varnish. The style traversing over this sheet in a succession of close lines produces upon a paper at the other end, moved with the same velocity, marks which reproduce the original writing or drawing.

The advantage of mechanical transmission is that while the preparation of the message takes, of course, much longer than the direct process, many such messages may be prepared at the same time. But the actual transmission along the wire is limited only by the capacity of the receiving apparatus to record the signals, so that one wire and set of receiving instruments will do the work of many worked by hand.

1277. The process is also very valuable in measuring exactly the period of any action, which records itself on a paper moving with a fixed velocity. Thus the relations of inducing and induced currents may be made visible upon papers travelling side by side, with styles connected to the primary circuit and the two ends of the secondary.

1278. Electric Organ.—In this the access of air to the several pipes or reeds is controlled by an electro-magnet attached to each, instead of by rods and levers actuated by the pressure on the keys. The keys themselves have no mechanical work to do; they are simply "breaks," and act by closing the circuit of a wire from each key to its corresponding electro-magnet. The work of the performer is therefore far less laborious, and his touch much lightened, while the keyboard, not forming a mechanical part of the instrument, can be placed in any convenient spot, or in fact, at any distance whatever from the music-producing instrument.

1279. If a receiving instrument is arranged with the style and connecting wire for each key and stop of an organ, &c., when the key is pressed down a mark is produced, which records exactly the kind and duration of every musical note produced. The keys of a pianoforte, and indeed of most instruments, can be so fitted as to record the musical thoughts or experiments of the composer, or to exhibit to a teacher, if required, the progress and work of a pupil while practising. The record so produced would resemble the perforated papers now used in automatic musical instruments.

1280. Edison's Motograph.—This is a modification of Bain's chemical telegraph, based on the discovery that some liquids render the paper *slippery* when current passes: as this implies less resistance to a mechanical pull, it enables motion and sound to be produced at a distance without the aid of electro-magnets or of any mechanism to be actuated by the current itself, as the motion of the drum is produced by mechanical means at the receiving station. Caustic potash gives the best results.

Edison's loud telephone is based upon this action, and it was at one time imagined that an E M F was set up, as moistened chalk cylinders generate current on being moved: the real cause was the chemical action on the brass axis of the cylinder; the points pressing on the chalk surface were immediately "polarized" by a film of gas, which motion immediately removed, and permitted current to pass.

1281. Electric Bells.—These have the great advantage over the old fashioned house bells that their wires can be carried anywhere, and require nothing beyond support: against this is to be set the maintenance and trouble of the battery. Electric bells very frequently fail to act, owing to the want of proper adjustment of the means to the desired end. This involves three considerations: (1) the source of force, the battery; (2) the conducting wires; (3) the bell itself, and these are inter-related; they must be adjusted each to the other, not each considered as an independent matter.

1282. The *battery* should be one not needing much looking after and not liable to speedy exhaustion. Only small currents are required for a single bell, therefore small cells are suitable to one or two bells, but the size must be proportioned to the number of bells likely to be in action at once, and it is better to use large cells, where needed, rather than several small cells coupled as one. One battery properly adapted will supply a large demand on it, but in some cases it is better to have two or more independent batteries, so as to avoid long conducting wires. The battery may be placed anywhere out of the way, where not exposed to freezing and not liable to have its liquids speedily dried up; therefore it is best contained in a closed box of its own: great care should be taken also to prevent the cells from getting wet and setting up local circuits. Manganese cells are generally used, and the "dry cells," § 274, are convenient for private houses; but where the work is heavy, chromic acid cells, of the type called Fuller's are better. The cells described, § 267, will serve where there is not a heavy call, but as they must be exposed to the air, they will require occasional attention by supplying fresh water to compensate for evaporation. Whichever battery is used, the number of cells in series must be such as will, after being short circuited for a minute, freely work a bell through the circuit and it is wise to use a cell more than is required, rather than risk failure.

1283. The *conductors* may generally be No. 20 wire, but larger is preferable. It is necessary for one of the wires to be perfectly insulated; it is better for them both to be so, in case of accident; but if one is perfect in this respect, the other may be a naked wire, led anywhere and stapled to the wall. But where it is intended to use telephones, which will certainly come into general use by and by, it is important to have the two wires side by side to avoid induction, and both insulated. A convenient wire for these purposes is made with a No. 20 covered wire, and a No. 18 bare wire placed side by side, and covered with cotton as one; this, being passed through melted ozokerit asphalte, is very fairly protected against damp, and may be secured to the plastered walls by staples. A better plan is to let into the plaster the zinc tubes used for bell wires and draw the conductors through this, and probably the most perfect plan, where convenient, is to carry such tubes straight up the walls into the roof, from each set of rooms, so that any desired connection can be made, at any time, by tacking wires along the rafters from tube to tube. In this way a complete system of bell and telephone communication could easily be arranged, and if desired, clocks, in the different rooms, could all be worked from one driving clock in the hall or elsewhere.

1284. Double wire is not always desirable for such a circuit, intended to include several instruments, as the wire may leave one pole of the battery and travel singly all through the circuit, returning to the other pole. In fact the circuit must be arranged to suit its purpose: and in such a house system as referred to, it would be unwise to attempt to make one circuit serve too many purposes: it would probably be better to provide a common "return" circuit of a stout wire, connected to the negative pole of all the batteries, if more than one were used, and then carry insulated wires, as required, to constitute the independent circuits. Those who have studied the principles explained in other parts of this book, will have no difficulty in doing this properly.

1285. An example or two may, however, assist some, and the connections of an annunciator system will serve the purpose. Let us suppose that from every room in a house it is desired to communicate with the kitchen. A single "return," or as it is commonly called "earth," wire should be connected to the zinc of the battery, and then either traverse all the rooms, or pass from floor to floor with branches from it into each room: a wire should connect the + pole of battery to one terminal of the bell in the kitchen; the other terminal would then be connected to the annunciator or indicator system by a wire which would there be separated into as many independent wires as there are signal-magnets, one terminal of each of these being permanently connected in this manner to the bell: now an independent wire from the other end of the proper signal-magnet to its own proper room will complete the system.

The magnet actuated from any room, releases an arm and allows a disk to drop which uncovers the name or number of the room and leaves it so until the attendant has seen it and by pulling a string returned it to its place, when it is held up by a catch attached to the armature.

1286. The bell itself is subject to one principle of construction; it requires a specific amount of mechanical energy, which will depend on the volume of sound desired, and on the strength of the spring and the magnet which strikes the blow. The electro-magnet requires to be so proportioned as to supply this energy, § 983. Now this involves the adjustment of its wire to the battery: the energy may be obtained by a stout wire with few turns, acted on by a battery giving a sufficient current with a low E M F, that is from one cell, or it may be derived from a fine wire of many turns, receiving a small current from a battery capable of forcing it through the circuit. People who do not understand the principles appear to expect that any battery is to work any bell, and if it does not, they complain of imperfection and failure; but the failure is in their not properly adjusting the means to the end. See §§ 990–996.

1287. Electric bells are made on two principles, *single stroke* and *vibrating*, and they are made and sold so cheaply that they will hardly pay any one to make for themselves. The simplest construction, for a bell to hang against a wall, consists of a piece of wood with a pillar and screw to carry the bell: beyond this the horse-shoe magnet may be attached, by means of a block of wood glued on the base, so as to go between the arms, and a thin piece of wood crossing the magnet and tightened down upon it by a wood-screw. A metal stem just beyond the magnet carries a spring to which the armature is attached, adjusted so as to play over the required space to give the stroke. The hammer is carried on a strip of elastic metal attached to the armature, and so adjusted that when at rest against the magnet the hammer is just clear of the bell: the actual blow is given sharply, by the momentum given to the hammer overcoming the spring of its support. The distinction between the two kinds of bell commences here.

(1) *A single stroke bell* acts by the connections to the two

circuit wires being made direct to the two ends of the electro-magnet wire. The stroke is made as often as required by the person actuating the bell.

(2) *A vibrating bell* has a break similar to that of an induction coil, § 1132. The circuit is made from one wire to one end of the magnet-wire, the other end of which is attached to the pillar which carries the armature. The other circuit wire is connected to another pillar carrying a spring, the end of which carries a platinum point facing a piece of platinum on the armature, the distances being so adjusted as to produce the desired rate of vibration and length of stroke; the object of the spring is to maintain the contact long enough to secure the full magnetism being attained. These bells continue striking as long as the circuit is closed at the other end.

1288. *Pushes* are contact makers, which may be of any convenient construction. The ornamental ones made for sale consist of a piece of hard sheet metal which is cut into a spiral with a plate in the middle, which, when pressed down, touches a plate to which one wire is attached, while the other is attached to the spiral itself: a loose plug rests on the outer side of the plate and passes through a hole in the cap which screws down on the base, after it is fixed in its place by screws passing through it, and holds all in position.

1289. *Two pieces of metal* insulated from each other, may act by being pressed together at their ends, and this is the best *self-acting circuit-closer* that can be fitted to doors and windows to ring when they are opened or shut as desired, according to the position in which they are placed, being let into the wood with the one plate projecting sufficient for the purpose: thus, at a door, if to ring when shut, they should be let into the stop against which it closes, or behind the back of the door; if to ring when opened, they should be over it and standing out, with the outer end prolonged and turned back so as to receive the door again as it closes.

These make the best of *burglar alarms* if fitted in the floor, in likely places, under the carpet, the circuit of the whole being closed by one connection when fastening up for the night.

1290. *To protect a whole house*, such a pair should be fitted to every desired point, with a battery and bell in the spot where the alarm is desired, and a switch to turn it off when not required. The resistance should be large and the alarm made accordingly, because a constant current will be passing; the alarm should not ring the bell itself but act as a *relay;* that is, its armature should be held to the magnet, and when not so held will close a circuit from the battery to the bell by springing back against a stop. Now when the place is shut up, the observer will turn his switch on, and if all is right, the armature will be at once drawn up to the magnet, and then the bell can be turned on, unless the switch is made to close the two circuits at one action. If by any negligence any place is left unfastened, the bell will ring and give warning, and will do so at any time should a door or window be opened. Of course by the more complex system of § 1283 the apparatus would at once indicate at what point to look for the defect, or a local alarm would also act.

1291. *Switches* are instruments for directing current to one of several instruments. For experimental purposes, nothing is better than a piece of wood with a hole in the middle, and a ring of equidistant holes to contain mercury: a bent wire connects the required hole to the circuit, and wires from each instrument may dip in the separate cups: such a switch is shown Fig. 43, § 361. A more elaborate instrument may be made of a block of wood, with a pair of binding-screws for each instrument, and a pair for the battery; one of these last is connected to one of each of the other pairs; the other battery screw is connected to the central point; this may be a pillar with a spring traversing a series of blocks connected each to its proper screw, or it may be a block of brass surrounded with a ring of segments as described § 437, Fig. 45. An efficient rough instrument can be made with round-headed brass screws, the central point being a similar screw passing through two brass washers with the spring between them; the leading wires can be soldered to the screws on the under side, or to plates of copper either below or on the face, to which the screws make contact.

1292. *Compound Switches.*—Where it is required to be able to connect any one of several circuits to any one of several others (as in telephonic exchanges), a flexible conductor with a plug at each end can be used; for a moderate number, the simplest plan is to arrange a set of metal strips on a board, with a second set crossing them, but not in contact; holes are bored at each crossing so that a split plug can be passed through and make connection.

Now-a-days switches of all kinds are articles of commerce, almost to be obtained at an ironmongers, but the above descriptions will be of use to those who wish to make their own appliances.

1293. TELEPHONY.—Until recent times it was believed that the production of articulate speech required a complex organism; yet every echo taught the contrary. However, until speech actually issued from the diaphragm of the telephone, people overlooked the fact, that every sound, in crossing space, is resolved into *vibrations of the air*, and that the production of sound, musical or articulate, only requires an initial motion which can set up those vibrations. An echo is due to a surface which receives and reflects or reproduces vibrations in the air. If we hold a sheet of stiff paper in the hand we feel it trembling in answer to any sound, and those tremblings, if analysed, represent the sound, and if properly applied will reproduce it.

A strained diaphragm such as a tambourine, answers even more perfectly than the sheet of paper, and proves that articulate speech can be produced by a mechanical vibration. It can even translate the vibration into a visible record, which was done by Young in 1807.

1294. Scott's *Phonautograph* is the best known instrument for the purpose; it is a large cone to collect the sound, with a diaphragm across its base; to the middle of this diaphragm is attached a point which rests lightly against a cylinder covered with a layer of smoke, which being turned, records the sound in a series of undulating marks; each sound having its own specific form.

1295. The *string telephone* carries the principle one stage further. Though introduced as a common toy since the discovery of the electric telephone, it long antedates it in practical use; unknown to science, it had been invented ages ago by the Chinese, was used by the natives of Ceylon, and has even been employed by English schoolboys for purposes of surreptitious intercommunication. It consists simply of a small tambourine connected by a strained string to another tambourine, each fitted with the cone of the phonautograph: it is, in fact, a phonautograph which, instead of moving a point and tracing a line, moves a string, and through it a second reversed phonautograph, which reproduces the original sounds.

1296. *Edison's Phonograph* carries us another stage; it is the phonautograph again, but the smoked cylinder is replaced by a groove covered with tin foil which records the motion of the style of the vibrating diaphragm, in waves, not only in one direction, as a sinuous line, but in all directions, as a waving groove. Like the string telephone it sets a second diaphragm in motion (or its own) by the point actuated by this groove; consequently it is able to effect this reproduction, not at the moment, but at any time and as often as is required, provided means are employed to transform the soft tin foil into a more enduring substance.

In the improved instrument a cylinder of a wax composition replaces the tin foil, and instead of the heavy diaphragms at first used, there are very small ones, and the instrument is generally fitted with two ear tubes.

1297. THE TELEPHONE.—This instrument has come into practical use almost from the day of its first real introduction, and unlike most inventions was perfected at once: but this only applies to the actual instrument—to Bell's telephone, which notwithstanding numerous claimants to improvement, remains the best for general use. It is not intended here to enter into an examination of the various claims to the origination of the telephone beyond the remark that it is pretty clear that Reiss fully conceived the idea, and made a working apparatus which, if not perfect, only required a little use to make it so; but his idea remained fruitless, though it may probably have been the germ from which the later successful instrument was derived. There are many people who, doing little themselves for the world, appear to find a pleasure in fancying they diminish the credit of a successful worker, by pointing out that some one had anticipated him, and the vaguest intimation of the possibility of something being done, is quite enough for these people. On the other hand, an idea once published and become as it were public property, becomes a seed which germinates in another mind, and that mind perfects it, possibly without an idea as to whence the fertile suggestion was derived, and without this origin in the least diminishing the merit of the person who has ultimately brought the idea to completion.

1298. The telephone is claimed as a French invention (most things are), made by M. Charles Bourseul in 1854. It appears that he stated that as electro-magnets could be made, and as sounds are virtually air vibrations, a flexible metallic plate could reproduce the vibrations, and if the plate "could be connected with an electric current in such a manner as to alternately interrupt and close a circuit, it would be possible to electrically affect a similar metal plate so as to repeat the vibrations of the first plate."

Evidently M. Bourseul saw that something *might be done*, but as evidently he did not see *how to do it*, and that is what invention means. Those who ultimately did it found that this notion of interruption of the circuit is just what will not do what is necessary.

1299. It is right to recognize the fact that Reiss really brought the telephone near perfection, and Prof. Sil. Thompson has done good work in demonstrating the fact; nor is it unlikely that the work of Reiss directly or indirectly influenced the mind of many people, and among them that of Bell while working out the subject. But we must recognize that Bell *did work it out*, and is its legitimate inventor. Equally certain is it that the completion of the practical system of telephony is due to Prof. Hughes, whose microphone, *freely given to the world*, is the basis of the numerous patents and so called inventions for the transmitting part of the system.

1300. *Gray's Harmonic Telegraph*, and other similar inventions, were a natural starting-point; they transmitted musical notes, and many important uses could be made of them which space will not allow us to enter upon; but musical notes and articulate speech have a fundamental distinction. Musical notes, § 1167, may be produced by an even succession of independent impulses, as in the *siren;* in fact a card drawn along the teeth of a fine saw will produce a note varying with the rate at which it is drawn: therefore an electro-magnet armature would reproduce such notes at a distance. But the production of speech requires a current not broken, but varying in quantity, or what is called an *undulatory* current: to produce this, the circuit must not be broken altogether, but one of two variations may be employed.

(1) The acting *electromotive force* may be varied.
(2) The *resistance* of the circuit may be varied.

The first is the principle of the Bell telephone used as a transmitter: the second is the principle of the microphone and its derivatives.

1301. The *fundamental facts* underlying the telephone are those studied §§ 525 and 1141.

(1) When a piece of iron is moved in a magnetic field, it disturbs the molecular magnetic balance of the magnet on which that field depends: in other words, the approach of a piece of iron to a permanent magnet causes a change in the internal molecular constitution of the magnet itself, § 1011.

(2) When this magnetic balance is disturbed, an E M F is set up in a wire coil surrounding the magnet, which will produce a current, § 1008.

(3) When a current is produced in such a coil by an external E M F it affects the molecular constitution of the contained magnet, and also modifies the whole field.

1302. The *first and typical* telephone system consisted of two such similar magnets whose armature was a flexible iron disc: the impulses of the sound waves move the receiving disc; the motion varies the magnetism, sets up a rising and falling E M F, and sends an undulating current to the second or speaking telephone. Here the same phenomena are produced in a reverse order, and motions set up in the disc which reproduce the sounds by which the first disc was moved. But the agent is "energy" passing through a cycle of changes as in § 877, and the motions which give the sound are complex, § 1112.

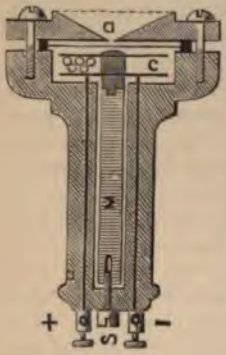
1303. The *currents of the telephone* are exceedingly small because they are related to the energy expended upon the disc in vibration, § 642, and this distributed over a circuit of considerable resistance: an ordinary galvanometer will not show them because they are of necessity alternating from instant to instant: but their existence may be proved upon a sensitive galvanometer by lightly pressing the disc, when a current in one direction will be shown, reversed when the pressure is removed. Mr. Preece estimates that a current of ampere 10^{-12} (a million millionth) is able to produce an audible sound. One consequence of the exceeding smallness of the acting E M F is that even imperfect insulation will not destroy the action, for telephones have been worked by naked wires lying on the ground. The two lines of a railroad have even been used as the circuit for a distance of several miles.

1304. *Battery Currents* were at first employed by Prof. Bell, as by all his predecessors, to actuate electro-magnets forming part of the circuit, while a "polarized armature," i. e. a permanent magnet attached to the vibrating diaphragm, by its motions varied the magnetic intensity of the electro-magnet, and by its reaction altered the rate of current passing, which therefore became an undulating but uninterrupted current.

1305. The next step, a simple and natural one when it was found how small a current would suffice, was to cut out the battery and interchange the core and armature, using a permanent magnet core, whose magnetic intensity was varied by the motion of the soft iron armature, which, being a disc of much greater diameter, collects the lines of force from the other pole of the bar. This idea appears to have occurred to Prof. Dolbear about the same time as to Prof. Bell. But as a matter of principle the difference is slight; it is merely a matter of convenience and expenditure, and the introduction of the microphone which requires an external current, has made the use of electro or permanent magnets a matter of indifference, except as to the relative importance of cost and the greater power of the electro-magnet. The regular current passing plays no part in transmission, it simply magnetizes the core; it is the *variation* of the current which does the required work, and the undulating current derived from the permanent magnet is the equivalent of that variation. The magnet is frequently fitted with a soft iron end upon which the current acts, because it is more sensitive to changes, as in fuze exploders, &c., § 1011, while the wire is concentrated at the end for the reasons given, § 981.

1306. CONSTRUCTION.—This will be understood by aid of Fig. 108; the magnet M is a rod of good steel highly magnetized, it may be 4½ inches long by ⅜ inch diameter, and is shown as fitted with soft iron pole-piece. It fits in the central tube of the wooden casing W, and is provided with a screw S to adjust its distance from the diaphragm D. On the end of the bar is placed the reel C, which may be 1⅛ inch in diameter with a space of ⅜ inch, to contain the wire, the size of which should be adapted to the resistance of the circuit, 35 gauge being the most generally useful: the ends of the wire are carried down through holes in the wood to the terminal screws + and —.

FIG. 108.



1307. The *diaphragm or disc* is usually made of ferrotype plate cut to a 2-inch circle, with great care not to buckle or distort it in any way, § 1300; it should be held by a narrow circle of india-rubber or soft paper above and below it, to deaden the natural vibration of the plate as a whole, as this causes most of the defects of the telephonic sounds, and their special "twang"; the fundamental note of the diaphragm itself keeping up a constant accompaniment to the induced vibrations.

The *mouth-piece* is a cap with a conical space ending in an opening of half an inch, so as to collect the sound waves and deliver them direct upon the centre of the disc.

1308. The *space between the disc* and the opposing surfaces should be no greater than just sufficient for the play of the diaphragm; this obviates the disturbance by resonance in the upper space and facilitates induction between the disc and the wire, which appears to play an important part in the action, § 1317. For this reason the slightly rounded end of the bar should only just project beyond the bobbin and should be brought as near to the disc as is sufficient to avoid any contact: this adjustment is best effected while a note is sounded in the instrument from an automatic break, so as to perceive the exact point at which the best result is obtained.

1309. *The Gower telephone* used by the post office consists of a steel horse-shoe magnet placed parallel with the diaphragm, with two soft iron pole-pieces projecting from its polar faces each fitted with coils: the effect is that the iron diaphragm takes up the whole of the field, which in the Bell form, as in Fig. 119, radiates over the diaphragm and through the air to the distant end. It would appear that this should be an advantage, and it is found practically that this is a highly efficient instrument.

1310. Others have aimed at a similar result by enclosing the instrument in a cylinder of iron, or with iron wires, closing the magnetic circuit from the distant pole to the circumference of the diaphragm.

Some inventors have attached the soft iron pole-pieces or cores to the diaphragm, so that they act on the plunger principle, § 372: magnetism is "induced" in these cores by a magnet near to, but not in contact with them.

1311. The diaphragm is made of thin iron sheet, the ferrotype photographic plates being generally used. Its thickness and diameter hold a definite relation to the dimensions of the instrument, and it is probable that improvements may be looked for in this direction. Small diaphragms answer as well as large ones if the true proportions are obtained, because, as with current, § 1108, powerful magnetic fields are not necessary, but sensitiveness to *fluctuations* in the magnetic intensity; sufficient thickness of iron is needed to freely develop the magnetic lines, and elasticity to give free movement under the slightest changes in the magnetic conditions.

1312. The early form of diaphragm known as the "English Mechanic" telephone escaped the claims of the patent through having been published in that paper, and consequently "disclaimed" when the iron plate was adopted. It has been used in many instruments for that reason, but has the disadvantage of varying in tension under atmospheric changes: animal membranes, gold-beater's skin, and various substances have been used, and it would seem by no means unlikely that some substance may yet be found which will give better sound-effects than the iron disc when combined with the double-pole magnets.

1313. ACTION OF THE TELEPHONE.—That the speaking disc should vibrate, like the receiving disc, is naturally to be expected; but for a long time it was denied that this was the mode in which sound was produced, and the explanation, § 1315, was favoured.

The mechanical undulation of the diaphragm, so small as for a long while to escape observation is, however, now proved. By arranging carbon rods upon the disc to act as a microphone, the sounds can be reproduced in another telephone, proving the variation of pressure.

1314. Experimenters failed at first to demonstrate these motions even by the delicate agency of reflected light; but this has now been successfully employed, by fixing a light mirror, not on the centre, but between that and the circumference. The most complete experiments are those of Dr. O. Frolich, whose paper may be found in the 'Electrician,' vol. 28, p. 59. He employed the method of Lissajous, receiving the reflected ray upon a rotating polygonal mirror, which greatly enlarged the motion of the ray as it was thrown upon a screen, producing a variety of curves, changing with the conditions: each kind of sound generating, as in other cases, its own special wave forms. It is obvious that the most delicate researches may be made in this way into the influence of induction and changes of form in the instrument. The telephone in this way becomes also a useful agent in examining the phenomena of electric currents, rate of alternation, impedance, &c., because these all vary the curves produced.

1315. *The amplitude of a sound vibration* may be inappreciably small, when the sound itself is feeble, as in those of ordinary telephones: in fact, it has been calculated that an amplitude of 400 millionths of an inch may suffice; but until these movements were demonstrated, the cause of the sound was sought in *molecular vibrations;* thus it is known that a bar of iron lengthens in magnetizing, according to Joule 1-27000th of its length; so that not only would the bar lengthen and shorten, but in so doing it would add this effect of approximation to that due to the magnetic increase, and so produce a motion of the disc which while ample according to the foregoing figures to produce a sound, would yet be far below the limit of visibility or measurement.

It has been argued that a molecular increase and decrease in the thickness of the disc itself is the source of sound, and thin as the disc is, the proportions would be adequate.

1316. *Iron in magnetizing and demagnetizing* gives out a sharp "click" to which the action is sometimes attributed, but interesting as the fact is, as an evidence that some actual motion occurs in magnetizing, which, if frequently repeated, even heats the metal, yet it appears unlikely that the undulating currents of telephony would produce that motion so suddenly as to generate sound.

1317. We know that *inductive or static charges* set up actual attractions as used in the balance electrometer, § 74, and that such charges are produced by and vary with electric currents, § 937, and that these charges and changes imply some action, involving motion in the particles of air between the two surfaces. There is good reason to suppose that this plays a part in the action, for there must be induced charges between the wire coil and the metallic disc, which collects in itself the lines of force. In fact, telephones have been devised which depend on this action alone, §§ 1319–20.

1318. The *thin iron diaphragm* may therefore be replaced, in some forms of telephone, by thick plates, or other metals and even non-metallic substances. The *iron core* even may be dispensed with. Sounds may even be received from a single plate of any metal connected to one conductor, and held by an insulating handle: in this case it is obvious that the action is purely one in the air between the insulated plate and the surface of the face, which forms the other electrode through the earth circuit. In fact, this is an elementary type of Dolbear's induction telephone, § 1320, which like many other matters here mentioned is of interest to the student of science, and to those who hope to carry practical work further, even though not at present made use of.

1319. *Varley's Condenser.*—This consists of an ordinary condenser made of a number of sheets of tin foil separated by double sheets of thin paper coated with shellac varnish; the sound is produced by the actual motion of the foils and papers, resulting from the successive attractions, together probably with undulations of the contained air. It was patented April 1870, and was mainly intended to assist in multiple telegraphy, the working out of which was in fact the object of the other telephone inventors.

1320. Prof. Dolbear carried the idea a step further in a telephone consisting of an air-condenser composed merely of two plates close to each other, each connected to one terminal of the circuit: its action depends on the principles explained, § 1318: as it requires a high E M F to work it, such as is derived from the induction coil, it is less subject to disturbance by surrounding actions, which are usually at a low E M F.

1321. Mr. Preece has shown that the varying temperature and consequent expansion and contraction produced in a wire carrying the current will reproduce sounds: he found platinum wire of ·001 inch, 6 inches long, stretched between a pillar and a diaphragm, to give the best results.

1322. The attractions between the turns of a helix, § 1134, either with or without an enclosed magnet, have also been proposed to vibrate a diaphragm, as also have been the polar attractions of the two arms of an elastic horseshoe magnet.

1323. If a bar of soft iron be hammered out flat for about half its length, sufficiently thin to vibrate pretty freely, and then bent first at right angles where it begins to thin, and curved over itself as a swan's neck, and a coil of wire be applied under the first bend, an intermittent current produces vibrations of the thin end, although the magnetic polarities are the same at the bend and its opposing end: this is because the return lines of force are greater in one case than the other, and also because the change of magnetism occurs more rapidly close to the coil than at the ends, so that for a moment there is a difference of polarity generated. Such an apparatus acts as a telephone if a disc of cork is adjusted to the vibrating end.

1324. The great difficulty of the telephone is that its extreme sensitiveness reveals electric variations inappreciable by any other means. It testifies to the slightest changes of magnetic intensity, or of electric current anywhere in its neighbourhood. This faculty is utilized in the induction balance, § 1384, and in replacing the galvanometer in the Wheatstone Bridge, and in testing changes as suggested § 1012; in like manner it proves that the currents from dynamo machines are not absolutely constant, and shows the intermittence of the action of the Holz and similar machines, and of vacuum tubes when the striæ are manifested even from a battery, such as described § 116. For such purposes two suitable circuits are wound parallel, or an induction coil with break screwed down can be used.

1325. TELEPHONE CIRCUIT.—As a consequence, the telephone is subject to numerous disturbances. The receiving disc may be disturbed by surrounding sounds or mechanical vibrations, as well as by the speech directed to it, but this may be guarded against. The varying currents passing in neighbouring wires will *induce* currents in the telephone circuit, and some very extraordinary instances of this are on record. The only sure protection against this is to use double wires of the same dimensions for the circuit, and these ought really to be twisted up as a cord, to ensure equal distance of the two wires from all surroundings. The rapacity of make-believe inventors has been fully exercised in this matter, and the most obvious expedients, such as would occur to anyone, have been coolly patented; even the mere use of a return wire circuit, instead of the "earth," was patented, though it is the universal mode of conduction, except where special conditions make the earth return advantageous purely for economical reasons. Different modes of exchanging the several wires carried on telegraph poles, so as to cause one section to neutralize the action in others, have been devised, and would be useful where even a difference of distance of a few inches from powerful currents would be of importance; but as a rule two copper wires parallel to and close to each other will show very little induction disturbances.

1326. *Impedance*, § 523, is the great enemy of telephonic and the metallic disc, which collects in itself the lines of force. In fact, telephones have been devised which depend on this action alone, §§ 1319–20.

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1323. If a bar of soft iron be hammered out flat for about half its length, sufficiently thin to vibrate pretty freely, and then bent first at right angles where it begins to thin, and curved over itself as a swan's neck, and a coil of wire be applied under table and then speak to the table, we shall feel a vibration due to the impact of the sound waves, and this is sufficient to produce a varying contact between the coin and nails; substitute for the table a better resonator or sound-board, or an elastic diaphragm, and for the nails and coins, pieces of carbon in variable juxtaposition, and we have the microphone, which as at first stated, to the surprise of the world, would make the "tramp of a fly" audible at a distance. In fact, it has been said, with scientific truth, that a fly, when it settles, shakes the world: that shake is however not appreciable, but each footstep of the fly will certainly vibrate a sensitive sound-board, and what is heard in the telephone is not the footstep of the fly, but a wholly new sound, the mechanical equivalent, not of the work done by the fly, but of a disturbance in an electric circuit in which strong forces may operate.

1331. Prof. Hughes gave this real discovery to the world, and he also gave the principle of arrangement, viz. that the number of such variable contacts must vary as the cells in a battery do, in series for small currents and large resistances, in parallel for larger currents; that is to say that each such variable contact will only transmit or vary a limited current. But inventors and patentees seized upon every imaginable variation of arrangement, with the result that actually used transmitters are known by the names of their arrangers, while all are but forms of Hughes' microphone.

1332. *Reiss's original transmitter* is a close approximation to the microphone: it consists of a light balanced lever, one end resting against the diaphragm, the other closing a contact, which if made against an elastic face would produce varying pressures rather than actual break of circuit, or might introduce a mere film of air, remaining a conductor as in the arc.

The microphone takes, in fact, just that slight step by providing contacts which vary in number and pressure, and therefore gives the conductance of the circuit an undulating character.

1333. *A sensitive form* consists of a vertical sound-board or diaphragm on which are secured two blocks of carbon connected to the circuit: in each of these a small conical hole is formed to receive the conical ends of a light stick of carbon. The *Gower* microphone in England, § 1341, and the *Ader* microphone in France have been most largely used; they are perfectly alike in reality, each consisting of a number of rods of carbon, connecting terminal blocks of carbon: in the Ader they are arranged in rows between the blocks, in the Gower they are radial.

1334. *Edison's transmitter* produces an undulating current by varying the resistance: this is effected by pressure exerted by the diphragm upon a block of carbon composed of compressed lampblack. Mr. Edison claimed the discovery of this changeable resistance as made by him in 1873 and utilized in producing rheostats acting by varying pressure upon powdered carbon in glass tubes. There is no reason to doubt the actual discovery, but, like many other supposed inventions, the fact itself was public property, having been published by Du Moncel in 1856, and rheostats were made on this principle in Germany in 1865. But the fact has been very usefully applied by Mr. Edison not only in telephony, but in other delicate instruments, such as the micro-tasimeter, § 1386.

It really operates in the same manner as the various microphones, though Mr. Edison at first thought an actual variation of conductivity occurs; but it is now known that the effect in all cases is due to a more or less perfect, or greater or less surface of contact.

The external form is similar to the Bell telephone, but the movable rod which replaces the magnet is only of use for adjusting the initial pressure: on this is laid a platinum plate connected to the circuit, then the block of compressed carbon, covered by another platinum electrode, and a plate of ivory or glass: in the middle of this a brass cylinder (which replaces an india-rubber block at first used) transmits the motions of the diaphragm, or the varying pressures due to the impact of the sonorous waves when a more solid or non-vibrating plate is used. It has gone out of use, the microphones proving the best in work.

1335. *Cuttriss's carbon helix* is the latest modification: it consists of a helical spring composed of a carbon filament like those of lamps, so formed that the turns have varying pressures upon each other according to the play of the diaphragm to which it is connected at one end, and the adjustment of a screw at the other end. It is stated that a helix weighing only 1 grain and exceedingly mobile will vary in resistance from 10 to 500 ohms. At the time of writing this, only a preliminary description has been published.

1336. *Transmitters in which the resistance varies* permit the use of induction coils, the transmitter replaces the contact break and sends undulatory currents from a battery into the primary of the coil, while exactly similar undulations are produced in the secondary wire: these however have a much higher E M F than those of the battery, and are adapted either to sending currents through a high resistance, or to working condenser telephones by "charge."

1337. THEORIES OF MICROPHONE ACTION.—There has been much discussion on this, and several explanations are maintained; as (1) a variable resistance due to compression of the carbon itself—this is now entirely disproved; (2) variation due to alteration of the number of molecules, or area of surface in actual contact; (3) variation due to pressure of air film preventing absolute contact, but itself acting as a conductor; (4) the formation of an *arc* of varying resistance, in such an air film; (5) an intermittent make and break of circuit. The last two may appear alike, but there is an essential difference of principle between them, dependent upon whether the circuit is actually broken and current stopped, or whether there is merely a rise and fall of conducting capacity, never interrupted, with a consequent undulating current.

1338. The *air film* theory, and that of *actual contact* differ, and yet agree, for the question arises, *What is actual contact* in this aspect? All surfaces have a film of air (§ 735) on their surfaces, while carbon possesses special powers of condensing gases. Microscopic examination tends to show that there is a slight separation, and even a repellent action, and Mr. Stroh has estimated that a space of 1–2000th of a millimetre exists in a delicately balanced microphone: it seems improbable that such can be the case where, as in the Edison and Blake transmitters, a considerable initial pressure exists. Messrs. Probert and Soward appear to have proved, in a paper read April 12th, 1883, to the Society of Telegraph Engineers, that this film does exist, for they arranged a microphone contact in a vessel through which they passed streams of different gases and found a difference of resistance, viz. moist air 386 ohms; dry air 520; carbonic acid 435; and hydrogen 600, with corresponding effects in reproducing sounds.

1339. *But such minute films are conductors:* that is to say, electric transmission takes place across them just as it does through a moderately good conductor of high specific resistance, though this may be, for air, greater than that of carbon, as this is greater than that of silver: or it may be simply a question as to the distance at which the molecular actions can occur, and produce electric transmission. But we know that such films do not arrest electric transmission, for even the low E M F employed in electro-metallurgy surmounts them. A piece of gold fresh cleaned receives an adherent coating of copper; if we leave it exposed to the air to reform its film, we can still deposit copper on it freely, though the coat will not adhere: we have here the distinction between *molecular contact* and circuit *across an air film*, but it is evident no *arc* can accompany this transmission.

Professor Blyth has however proved that an arc may be formed in the film of air and will act as a transmitter, but he used an E F M altogether out of practical range. It is also known that a variable arc lamp will give rise to sounds in a telephone.

1340. *Equal variations of pressure do not produce equal changes of resistance.*—Mr. Shelford Bidwell published a very full series of experiments which show that the greatest variation occurs while the pressure is small, and that a limit is soon reached at which little effect is produced: it would appear as though the early action is to thin and squeeze out the air film, then to press more surfaces together until the limit of elasticity is reached.

He also found that the *resistance varies with different currents:* therefore there is something besides resistance to be considered. The resistance *varies most* with small currents, pressure being constant, but is lowered by the increase of current, pointing to an action of the heat developed at the contact, which is not readily conducted away, because carbon is a bad conductor of heat.

1341. PRINCIPLES OF CONSTRUCTION.—The adjustment and the resistance must be suited to the required purposes: for very slight sounds or motions the moving parts must be very light and the capacity of motion very delicate: but if such an apparatus were used to transmit speech, little more than a continuous roar would be heard. For this purpose heavier masses, greater pressure, and, as Prof. Hughes indicated from the first, several separate junctions are required, as used in the Gower transmitter. This consists of a sound-board, to the middle of which a round block of carbon is attached, having six conical holes around it; six corresponding blocks are arranged in a circle around the sound-board, and pointed carbon rods connect them: three of the blocks on each side are connected together, and to one terminal, so that the system acts as three pairs of contacts in multiple arc, and two in series.

1342. The principles for a speaking microphone may be conveniently stated nearly in Mr. Bidwell's conclusions from his experiments: (1) the constituents (moving carbons) should be numerous. (2) They should all be in multiple arc. (3) They should be heavy, to give inertia. (4) The pressure should be light, by adjustment. (5) The resistance should be small, and adjusted to that of the whole circuit. (6) The current should be large in the whole but small at each contact.

1343. DISTANCE OF TRANSMISSION.—There appears no reason why *mere distance* should be of any moment, nor the mere resistance of the circuit, and this leads enthusiastic people, who fancy that there are no limits to scientific possibilities to imagine that it will yet be possible to talk through Atlantic cables. The limiting laws are however now pretty well understood: the obstacles to transmission are internal and external, *inductance* and *induction* resulting in the confusion described § 1326.

1344. *Induction*, the influences from without, of electric and magnetic changes reacting within the wire, may be wholly got rid of by great care in arranging the circuit, and mainly by securing equal opposing actions within the circuit; spiral winding of the conductors in cables, and an equivalent change in aerial wires at the supports, as is now done in the Paris and London line, will pretty well neutralize external actions.

1345. *Inductance*, the internal reactions of the circuit itself, cannot be entirely disposed of, as it is an inherent part of conductance, § 469. The undulations of speech involve about 1500 changes of current per second, and every one of these means a change in the static and magnetic charges of the circuit.

1346. The *limiting law* is very simple and depends on the "product of the resistance and capacity" of the line—K R. According to Mr. Preece, who carefully studied this subject while preparing for the Paris line, when

K R = 15000 speech becomes impossible
" = 12000 " " just possible
" = 10000 " " fairly good
" = 7500 " " very good
" = 5000 " " excellent
" = 2500 or less, speech becomes perfect.

The E M F or current does not affect this because they and the disturbances rise and lower together: but the sensitiveness of the receiving instrument does influence the limit at which it can be employed.

1347. The *capacity of the line* depends upon its material and its mode of insulation, and those who wish to study the subject will find the details in Mr. Preece's paper to the Royal Society, 3rd March, 1887. He gives the *law of limit of distance* as $x^2 = A/KR$, where A is a constant for each material

Copper, overhead	15,000
" in cables	12,000
Iron, overhead	10,000

The result is that the material must be copper, and the possible distance is inversely as the square root of the line value K R.

1348. The *Paris London line* has proved the truth of these principles by its most perfect working, and some particulars may be of interest. The English land line is 400 lb. copper to the mile carried on posts 70 yards apart and 25 feet from the ground. In the English portion the two wires of the circuit make one turn every four posts, and in the French part in every six, and the English part works rather better than the French. The French line is 600 lbs. to the mile, but it is injured by a length of underground cable where it enters Paris.

The *cable* contains 4 circuits, each a strand of 7 wires 160 lbs. per nautical mile of 7·50 ohms resistance per mile, insulated with guttapercha and Chatterton's compound, with insulation in water of 500 meg-ohms per knot and a capacity of 0·3045 microfarad per knot, and the several cores are twisted in a spiral.

1349. The details of the several portions are:

	Miles.	R ohms.	K mic-far.
London to St. Margarets. ..	84·5	183	1·32
Sea cable	23·	143	5·52
Sangatte to Paris	199·	294	3·33
Paris underground	4·8	70	0·43
	311·3	693	10·62

$$KR = 693 \times 10{\cdot}62 = 7359.$$

1350. The line has been connected to Marseilles, a further distance of 900 miles, through which speech was possible, though difficult because the line was not specially constructed for the purpose.

In America speech is common over great distances, but in these cases the lines are wholly aerial and carried over country with little disturbing influences. Where cables and underground wires are used the difficulty becomes much greater, simply because of the inevitable increase of the capacity K.

1351. Telephone Systems.—Space will not permit the description of the arrangements of the regular telephone "exchanges," nor is it necessary, as those concerned in them must abide by the arrangements in each case. They involve the subdivision of an area into districts, at each of which there is a "switchboard" by means of which the attendant connects any required circuits together so as to enable any one subscriber or station to communicate directly with any other, whenever the condition of the line and instruments permits theory to become practice.

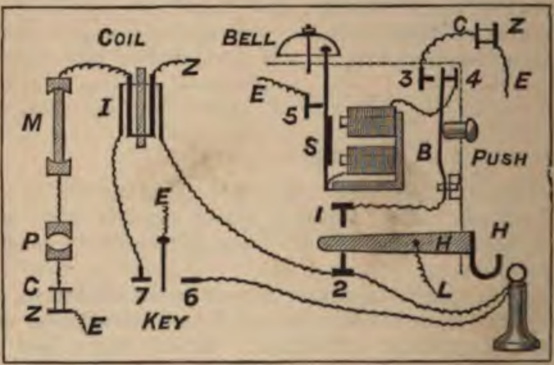
1352. But it may be useful to show such a system as any person can employ for personal requirements. The actual apparatus to be employed will be readily selected and made by those who comprehend the general descriptions already given, and who are capable of such work, while there are plenty of manufacturers ready to supply suitable apparatus to those who require their aid.

A *call* is a first essential, and many attempts have been made to make the telephone itself serve, but the ordinary bell is generally used, now that battery currents are again employed.

The call may be actuated direct, or a relay can be used to set a local battery in action; with a polarized armature this will also enable the speaker to select which of two instruments he may desire to address, according as he sends positive or negative currents to the line by means of a reversing commutator.

1353. Fig. 109 is a diagrammatic explanation of the principles of a complete circuit, the actual arrangement of which may be greatly varied. L is the line wire connected to the movable lever or spring H, upon which the telephone is hung when out of use, so that its weight shall place H in contact with the point 1 and the call system: this circuit then passes by the spring B to point 4 connected to the electro-magnet, and then through the vibrating spring S to E. E represents the earth-plate or return wire, to which various connections have to be made.

Fig. 109.



If the other instrument is to be called, the push puts B in contact with point 3, by which the positive pole of the battery C is put to line; Z, the negative, being permanently to earth; this sends out a current which acts as just described in the other instrument.

Unhooking the telephone puts the speaking system in circuit, as shown, by means of a double contact key or switch, put on point 6 to receive, and on point 7 to send a message, its moving arm putting either the telephone or transmitter to earth as required.

The transmitter, of whatever form, shown as a simple microphone M, is connected to the battery through a switch or plug P, to cut it off when not in use, the current passing through the primary of the induction coil I, and to the zinc of the battery. The secondary wire completes its circuit through point 7, and the switch, to its own earth, and through point 2 and H, to the line and the distant instrument earth.

If a simple telephone is used to speak through, its second wire is put to earth instead of to point 6, and the one telephone employed for both speaking and hearing, or two connected in arc or series, may be employed.

1354. The Post office engineers find that the best construction of induction coil for this purpose consists of 180 to 185 turns of No. 23 gauge and ·5 ohm resistance for primary, and 4100 to 4330 turns of 28 wire, of 250 ohms, for secondary: but of course the coil ought to be adjusted by the ordinary laws to the conditions of the circuit it is to be used with.

1355. Radiophony.—One of the most interesting of recent discoveries, on scientific grounds, is the extreme sensitiveness of matter to the smallest variation in the streams of radiant energy. To the ordinary perception it appears that changes of temperature require considerable time to produce any effect upon matter, but we have now learnt that they are attended with great molecular changes, modifications of structure and properties, which occur with a rapidity comparable only to the speed of light, and which show, as stated § 1040, that each molecule of matter is the centre of action of many forces, and swayed instantly by any change of relation among those forces.

1356. *Sound*, as explained §§ 1166 and 1293, is simply a *vibration* which is perceived and measured by a special organ, the ear, but which may also be seen and felt. Like light, it involves a *source, a mode of propagation, and a receiver*, and like light it may be propagated in circular waves around its source, or concentrated in a "beam." Its vibrations may also be taken up by a resonant surface, such as a sound-board, which then becomes a new source.

1357. *Wheatstone's lyre* illustrates the principles to be borne in mind. If a musical box be set playing, its sound will not be heard in a room several stories above, even if a small opening be made through the several floors; but if through these openings there passes a light rod of pine-wood, resting on the box, or a resonant table on which the box stands, and terminating above in a sound-board, then the music will be heard in the upper room. The reason is, that air is actually one of the worst transmitters of sound, though the usual means of transmission: pine-wood transmits sound much more freely, and with about sixteen times the velocity. It is on this principle that the "stethoscope" is based, and enables us to hear sounds in the interior of the body, which cannot be perceived by the ear alone.

1358. A beam of radiant energy may be compared to the rod of Wheatstone's lyre, or to the cord of the string telephone, which transmit a stream of energy, and the essential point of radiophony is that, if the stream of energy is made intermittent, the intermissions correspond to the successive impulses in the rod or cord, and that such impulses, falling upon a surface, may excite such momentary expansions and contractions as will generate sound-waves, just as though the resulting molecular undulations were caused by an actual vibration. This effect is in fact identical with that considered as occuring in the telephone, § 1213.

1359. The *simplest interrupter* is a metal disc mounted on an axis, and with a number of equidistant holes formed near its edge, the beam of light being condensed upon the point cut by the holes when the disc is rotated. Now this is one form of "siren"; for properly fitted, with a stream of air directed on the holes, we produce a musical note, varying with rate of rotation. In like manner, if we make the disc of iron, and place an electromagnet with a telephone in its circuit on one side, and a magnet pole on the other, we have the *magnetophone*, which produces the same notes. We thus trace the connection from the rough mechanical actions through the hidden actions of light and magnetism, just as in §§ 982–6 we trace the analogies of wave motion from the surface of a pool to the glories of the spectrum.

1360. *The radiometer*, when first invented by Mr. Crookes, was supposed to move by the impact of streams of radiant energy, as light; but it is now well understood that the motion is due to a more material impact, to the succession of blows given by molecules of the residuary air in contact either with the walls of the globe, or condensed upon the moving vanes and acting by "recoil," these molecules absorbing the energy of the radiant force. This same action is that which is operative in radiophony proper. The vanes rotate on their axis because their two sides have different absorptive powers, and therefore there is always a tendency in the most active side to retreat from the line of light, just as a horizontal windmill rotates in a stream of air because the vanes on one side present a flat surface to the wind, while those on the other side lie edgewise to it.

1361. One of the most remarkable experiments of Mr. Crookes is that of a radiometer with vanes coated on one side with selenium, and on the other with chromic acid. He found that light from a sperm candle, giving white light, repels the selenium, while that of a wax candle, with yellower light, repels the chrome, indicating the relative absorptive powers of the different substances for rays of different refrangibility, resulting in mechanical motion, just as the same selective power operates in photography as chemical action.

1362. If a radiometer disc were mounted on an elastic support, and placed at right angles to an intermittent beam, it would doubtlessly vibrate to and fro in unison with a stretched cord giving a note corresponding to the intermissions: it would not produce *sound*, because sound cannot traverse a vacuum, unless the varying tensions on the glass might result in sound, but a beam of reflected light would show the motion. Something analogous to this occurs in direct radiophony, § 1378, but both for order of discovery and for convenience of explanation it is better first to examine the indirect action through the aid of electricity by means of selenium.

1363. SELENIUM.—This substance, which is chemically of close kindred to sulphur, manifests in a most striking degree the instant variation of the properties of matter under changes of external forces. Like sulphur, it passes into several different states, according to the conditions of fusion: it may be amorphous or vitreous, when it is non-conducting, and insoluble in bisulphide of carbon; or when very slowly cooled after fusion, it becomes crystalline and conductive, and also soluble; changes resembling those of phosphorus.

Willoughby Smith, while trying selenium for large resistance measures in 1873, discovered that this resistance was variable, and traced the variation to the action of light; he used a bar of selenium with platinum wires melted into its ends, and found the resistance of 1400 meg-ohms when the room was dark, reduced to 1000 when the gas was lighted.

1364. It has now been ascertained that the rate of variation of resistance under light is as the square root of the intensity of the light, so that it was proposed to use selenium in photometry: but unfortunately the property is not constant, but varies spontaneously as does the actual resistance. Prof. W. G. Adams has found a variation from 1,525,000 to 3950 in 12 months, and in another piece from 7,600,000 to 745, without any use having been made of them in the interval. Others have found similar fluctuations.

1365. There have been debates as to whether the action is due to light or to heat, really a discussion without meaning; but it would appear that the power is exerted by particular rays of the spectrum, as indeed is almost universally the case with radiant energy. The most active rays are those found on the green side of the yellow rays; but some experimenters have also found an active region in the ultra red or dark rays, and when a ray of sunlight is intercepted by a sheet of ebonite, an invisible beam passes which may be condensed upon the selenium cell; if a perforated wheel now renders the beam intermittent, the apparatus gives out the musical note in the telephone.

But *temperature*, as distinct from radiant energy, acts differently and apparently not alike in all samples. Some find resistance increase with heat and some find it decrease, and there is reason to believe that each sample has a "critical point" at which a reversal occurs, just as in thermo-electric actions.

1366. There appear to be several distinct actions: (1) light produces a gradual reduction of resistance, which gradually falls on withdrawal of light; (2) there is an instant decrease and as instant a recovery, these being the actions utilized.

There are different opinions as to the cause of these changes.

(1) Dr. Moser claims that there is not a true union between the metal and selenium or selenide, but only a microphonic contact modified by expansion and contraction.

(2) Siemens considers that besides the two allotropic forms, § 1333, amorphous and crystalline, that there is a third, *metallic.* He found that at 80° C. one change occurs accompanied with a loss of latent heat or energy, and another at 200° C. attended with a further loss, but that only a small part of the mass can undergo this change, which is also very unstable. He attributes the action to this last change occurring among the superficial molecules under the action of light.

1367. *Light generates an E M F in selenium*; this has been noted by several observers, but most fully studied by Fritss, § 1370. He found that platinized glass made the best electrodes, and is transparent to all the rays of the spectrum. The selenium was melted between two plates fixed at suitable distance apart, cooled under pressure, heated two or three times up to 195° in a paraffin bath and slowly cooled. The platinized glass is that which is prepared for mirrors and decorative purposes, the platinum being fuzed into the surface of the glass.

An E M F of 0·12 volt is set up and the film is found very sensitive as to change of resistance, which is lowered to one-ninth of that in the dark. The action is attributed to changes of molecular aggregation, or allotropy, and to selenides always found to be present.

1368. *Selenium cells*, as the receiving apparatus are called, are made in different forms, the object being to obtain as low a resistance as possible, with a small surface to receive the light. Various metals may be used as electrodes, but silver will not suit, because it is strongly acted on by selenium, nor will aluminium, because the two will not unite at all; platinum is generally used as most permanent, but others prefer copper or brass: later experimenters find that selenides of copper are formed with these, which increase sensitiveness while they introduce elements of instability.

1369. *Mercadier's* early cells consisted of strips of metallic foil with narrower strips of paper between them, wound tightly in a spiral and the spaces filled with the selenium while the metal is heated to the proper point.

Mercadier's improved cells consist of a double spiral of platinum wire laid on fine emery cloth: this is laid on a mass of heated metal, and a rod of selenium rubbed on. Cells of 300,000 ohms have remained invariable for years.

For spectrum experiments the cell must be made into a narrow strip.

1370. *Mr. Fritss*, of New York, § 1367, made cells which Prof. Grylls Adams states lower in resistance to one-half, under the influence of a candle at one foot distance, and from 14,000 in the dark to 170 in bright sunlight; another lowered from 200,000 to 940.

1371. *Annealing.*—This was first effected by prolonged heating at 214° C., or the point at which the particular sample has the most conductivity (the fusing point is 217° C.), and then allowing to cool very gradually for many hours, some passing current all the time; careful warming is now found to be sufficient, taking care to avoid excessive heat, and watching the changes which occur till a granular surface of a slate colour is produced. A few minutes suffice for the process, but it may need two or three repetitions.

1372. *Sulphide of silver* is found to have similar properties, in some conditions; the best form appears to have been obtained by M. Mercadier by electrolysing a solution of sodium sulphide upon a silver electrode. A film of sulphide of silver is thus obtained which can be separated by warming the silver plate: it is laid upon a sheet of asbestos paper and two helices of iron, platinum or silver pressed upon it without heat. The resistance is much less than that of selenium, but only small E M F's can be used with it.

1373. Great expectations were based, some years ago, on these actions; we were going to see at a distance, as we hear by the telephone. But all this has died out, because the unreasonable anticipations were not at once realized; as immediate results have been attainable in other fields this has been neglected. Mercadier in France, and Shelford Bidwell in England are the only people who have cared to work at it: however it will come to the front again some day, and offers a good prospect now to the patient and earnest experimentalist, for whose sake I have thought it well to give so much space to a subject not of immediate importance. It may be noted that Mr. Bidwell has suggested the use of selenium in automatic lighters-up: he arranged a current to work a relay when the light intensity fell to a fixed point; this actuated a switch which turned on the electric or gas-light.

1374. PHOTOPHONY.—Willoughby Smith, besides discovering the action of light on selenium, was the first to "hear a ray of sunlight fall upon a bar included in the circuit of a telephone." Others also had conceived the same idea, and were working at it, but Prof. Bell in conjunction with Mr. Tainter was the first to perfect an apparatus to transmit speech by a ray of light, and to realize what he called "the extraordinary sensation of hearing a beam of sunlight laugh, cough, and sing, and talk with articulate words."

This is effected by producing undulations in the light intensity, corresponding to the air waves of sound, and by the use of selenium receivers of low resistance, such as 300 ohms when dark, reduced to 150 in the light.

1375. There are various modes possible for producing a ray of varying intensity, and as a matter of curious scientific interest, we may note the suggestion of passing the light first through a Nicol's prism, and then sending one of the polarized rays through a glass tube containing bisulphide of carbon or other rotatory liquid. The wire from a telephone being wound in a helix round the tube, the varying current caused by speech in the telephone would vary the rotation of the liquid, and therefore also the quantity of light passing. In this way a solution of sugar might be made to report upon its own saccharine value by the strength of a note passed into the sonometer.

1376. The *simplest transmitter* consists of a plane mirror of flexible material, microscope glass answering perfectly: this forms the front of a chamber fitted with a speaking tube, in fact resembling a telephone disc with its lower face made into a reflector, which would send a reflected beam of light through the space of the magnet. A strong beam of light is concentrated upon the middle of the mirror, and after reflection is received upon a condenser and rendered parallel, so as to be transmitted to a distant parabolic reflector which concentrates the rays upon the face of the selenium receiver. The whole ray passes thus when the mirror is quiescent, but the impact upon it of sound-waves distorts the mirror surface, and rendering it more or less convex, proportionally scatters the reflected rays beyond the edge of the condensing lens, and therefore varies the strength of the luminous beam transmitted to the receiver.

1377. *Musical sounds* can be more perfectly transmitted than speech, and any desired note can be produced by the perforated disc, § 1359. Such notes can also be converted into signals on the principle of the Morse alphabet, by means of a key, which interposes an opaque screen in front of the opening in the disc so as to produce periods of sound and silence to represent the dot and dash signals. Where, as in war, a beam of light might be a source of danger, a dark ray may be serviceable, § 1381.

1378. Direct Photophones.—Prof. Bell observed in his experiments, that the intermittent beam gave out sounds when simply falling upon a disc of resonant material, without the aid of the telephone. Further experiment in conjunction with Prof. Tyndall showed that nearly every substance tried in a thin diaphragm gave out sounds; attributing this to sudden expansions and contractions due to the absorption of heat, they tried vapours contained in a test tube fitted with a hearing tube: it was found that the vapour of sulphuric ether, which is powerfully absorbent, gave out notes, while bisulphide of carbon, which is dia-thermanous, was silent. We have here in fact sound produced by molecular vibrations, just as in the case of the telephone, § 1313.

1379. But it is very doubtful whether the sounds, or the molecular expansions resulting in sound, are due to the *surfaces* on which the radiant energy is received. It is found that a tube containing loosely packed spongy materials, which have no resonant properties, gives out the best sound, and also that a surface which when quite clean has little power, becomes sonorous when smoked, i. e. coated with lampblack, which is a well-known powerful absorbent of radiant energy. It appears therefore that the true cause of the sound is similar to that of the motion of the radiometer; that it is the energy taken up by molecules of air in contact with the receiving surfaces. As in § 1206, the energy traverses air itself without heating it, but the absorbent surfaces at once transfer the heat to the air in contact with them, and this air instantly has an impulse to motion which generates a sound wave.

1380. Mr. W. H. Preece suggested this explanation, and demonstrated it by using a case or tube containing a spiral of fine wire through which an intermittent current was passed: this, generating heat impulses, gave out a sound from the tube similar to those produced by the external ray. Perhaps even a more striking evidence is given by the action of a flask which filled with dry air gives no sound as a receiver, but does if filled with ammonia vapour, which absorbs energy: a difference which applies to the whole range of gases and vapours, which Tyndall, in his 'Heat as a Mode of Motion,' has shown to be divisible into absorbers and transmitters of energy according to the complexity of their molecular constitution, the more complex being "reduced" to simpler forms by the act of receiving energy, the fundamental law of chemical actions, and of the functions of vegetable life.

1381. The different capacity of different substances for absorbing radiant energy as light and heat is mentioned § 1201, and the fact that the same substance has very different relations to rays of different refrangibility, §§ 1166 and 1191. This is strikingly illustrated by glass, which freely transmits light rays, yet intercepts the long-wave heat rays.

Ebonite has just reverse properties: it is quite opaque to light, but in thin sheets a strong light may be seen through it, as a dull red colour; that is, it transmits the lowest of the red rays, and permits the ultra red rays to pass freely. If a sheet of ebonite be held in the path of the rays acting on a selenium receiver it prevents the production of sound, because the chief action on selenium is due to the yellow rays which ebonite refuses to transmit: but if the receiver is an ebonite disc or any material acting by heat, § 1378, the interposed ebonite produces little diminution in the sound. The effect is that an invisible beam of radiant energy falls upon the receiver, which may then be called a *thermo-phone.*

1382. THE INDUCTO-PHONE.—When two spirals of wire are placed parallel to each other, but unconnected, any current in one induces a current in the other, this being the basis of induction coil action. The quantitative effects vary as the square of the distance of two parallel coils, and the action is greatly influenced by those conditions which cause "retardation" and the number of breaks of circuit per second. Willoughby Smith applied this action, and examined its details in a paper read to the Society of Telegraph Engineers, 8th Nov., 1883, in which is traced out the influence of diaphragms of materials interposed between the two spirals. The effect of such screens is clearly due to energy absorbed and given out at each change of condition, and therefore varies with the *capacity* of the substance, and with the rate of the changes. The disc of a telephone acts as such a screen and actuates the telephone, and even gives out sounds by itself when placed in the lines of force. A small spiral traversing the face of a large one measures the lines of force proceeding from the different parts.

1383. TELE-PHOTOGRAPHY.—This apparatus for producing pictures or writing at a distance is an application of the properties of selenium, in combination with the chemical telegraph. In this, as described § 1257–8, a coloured mark is made at a distance when current is transmitted, and a facsimile of the original may be produced in the form of a series of dots and lines. A continuous current of greatly varied intensity would result in similar variations in the intensity of the lines produced; and such a variable current is producible by changes in the resistance, which changes are producible by light acting on selenium.

Mr. Shelford Bidwell made an apparatus for this purpose. The transmitter is a dark box, containing at one end a selenium cell forming part of the line circuit, and facing a small hole at the other end; the box is mounted on an axis, so as to move up and down, each upward motion corresponding to one rotation of the receiving cylinder, and so to one line on the drawing produced. The box also moves sideways at each stroke, to correspond to the distance of the lines apart. The face of the box corresponds to the screen of a magic lantern, and the picture to be transmitted is thrown upon it continuously, so that the pin-hole is, so to speak, an eye by which the selenium cells looks the picture over, and receives the influence of each part successively, as it traverses over the space filled by the picture. When a dark line is thrown on the hole, the resistance increases, while a white portion reduces it.

The transmitter is really a differential instrument: it receives the line current at one terminal, and that of an opposed local battery at the other, the line being also connected to the other pole of the battery, and resistances so arranged that the local battery acts and makes a mark whenever a dark lin produced, and thus the traversing style produces either no action at all, or coloured lines varying in depth of tone in correspondence with the amount of light falling upon the selenium cell from the distant transmitting illuminated picture.

1384. HUGHES' INDUCTION BALANCE.—This instrument is based upon the principles described, § 525.

(*a*) It consists of two straight-sided cups or cylinders of wood, or other non-metallic substance, mounted on a board at least 3 feet apart, and equally removed from any metallic masses. Each cylinder constitutes an induction coil, having two separate coils of wire (say, each 100 yards of No. 32) placed parallel to each other on the cylinder. Two corresponding coils, connected in series, constitute the "primary" or inducing system, in which is introduced a battery and any convenient automatic contact break, such as a clock, fitted for the purpose, the sound of which ought not to be heard, so that it is best in another room. The other coils are arranged with reverse action to neutralize each other, and a telephone is inserted in their circuit which will reproduce the tick of the break if there is the least inequality of induction in the two pairs of coils. A suitable galvanometer might be used to give visible instead of audible evidence, and would *measure* the action; but the telephone is the most sensitive.

(*b*) *Exact adjustment* is effected by making one of the coils movable, and fixing it at such a point as is found to give no sound in the normal condition, for which purpose the coils may be made on light reels, sliding on the cylinders, or the cylinders themselves may have a screw joint in their middles, by which adjustment can be effected.

(*c*) Now, if any substance whatever be inserted in one cylinder, if it has either inductive or magnetic capacity, it will disturb the equality, and sound will be heard in the telephone, varying in intensity with the capacity of the substance. If two masses of the same substance be placed in the two cups, any difference in weight or form will manifest itself.

(*d*) It is evident that if the principle of adjustment be carried further, a scale of induction could be prepared giving the quantitative relations.

(*e*) In the course of time important uses will be found for this instrument. Thus, it will at once test spurious coin, for if a good coin be placed in one cup and a suspected one in the other, the telephone will at once speak for its character. The chief difficulty is the great delicacy of the instrument, as a difference in weight will cause it to complain.

(*f*) It was employed to endeavour to discover the locality of the bullet in the case of President Garfield; but it was deceived by the presence of metallic springs in the bed. Undoubtedly such applications will yet be made. A splinter of metal in a finger has been discovered.

1385. HUGHES' SONOMETER.—This is a special form of the balance adapted for examining either the loudness of sounds or the capacity of any ear for distinguishing sounds. It consists of a graduated rod mounted on a frame. At one end of the rod is fixed a coil A, such as just described for the balance; at the other end, projecting beyond the support, is a smaller coil B, containing 1 yard of the wire. The two coils are connected in such a way as to have opposite, but of course unequal, effects upon a coil C, similar to A, and sliding upon the bar. Of course relative nearness will compensate for difference of power in the two coils, and the length of the bar (usually 200 millimetres) should be such that, when the moving coil C is placed close to the small coil B, the most sensitive ear shall discover no sound in a telephone included in the circuit of C, due to the breaks made in the circuit of the two fixed coils by a clock or other break, in the same way as described for the balance.

A scale of audition can thus be obtained, as an absolutely deaf person will hear nothing, even when C is fully influenced by A by being brought close to it, and others will begin to hear the ticking at different distances. The scale will also give a range of sensitiveness, as a certain distance will be found between the points at which a sound is lost, and that at which it is again perceived.

1386. EDISON'S MICROTASIMETER.—This measures the minutest changes of pressure, and therefore of heat, of moisture, and many other agencies. It is in fact the transmitter, § 1334, in which the vibrating disc is replaced by a rod of a substance to be examined. It consists of a solid iron bed with two brackets cast with, or fitted rigidly to it. To one is attached an ebonite disc with a central chamber; through the middle of this passes a flat-headed screw faced with a platinum disc which receives current from a binding screw on the bracket; on the disc lies the carbon button with another platinum electrode as in the transmitter, connected to the battery. On this lies a cup to receive the end of a rod of material to be tested, the other end being supported by a similar cup fitted on a slide in the other bracket, the position of which can be adjusted by a screw. Of course the arrangement might be vertical instead of horizontal. A suitable galvanometer is in the circuit, and the initial pressure is so adjusted that only a small deflection is produced.

A strip of ebonite placed between the cups shows extreme sensitiveness to heat changes which are not manifested by the thermo-pile: a hand held some inches away will give a deflection. A strip of gelatine produces the same effect by absorbing moisture from damp paper 3 inches distant.

For extremely delicate observations the instrument is placed in one arm of a Wheatstone bridge and balanced by a resistance. It would appear that the differential principle would be most perfect; two tasimeters balancing each other so as to neutralize surrounding actions, while the influence to be tested was concentrated upon one. However, the great difficulty of the instrument is its extreme sensitiveness. It ought to be placed upon a perfectly rigid support, free from all vibration.

1387. THERMO-ELECTRICITY.—The direct conversion of heat without the intermediary steam boiler, engine, and dynamo, is a tempting field for work, but so far, all known means are more expensive than the seemingly roundabout process, because the efficiency of conversion of energy is extremely low. Only about 2 per cent. of the heat is converted into electric energy. It would seem probable that by surrounding flues, chimneys and upcast shafts of mines with suitable thermo-electro elements, a good deal of waste heat might be utilized, or the reverse process has been proposed, to make stoves the casing of which generates electricity, while radiators diffuse the unconverted heat for purposes of warmth.

1388. Heat is a vibratory molecular motion, diffusing energy in all directions in equally conductive matter; electricity is a molecular motion transmitting energy in a linear path. Most substances have a similar conductive ratio for both, but for heat the conduction is slow, while for electricity it is instantaneous. The relation between the two appears to be, that electricity in its transmission always generates heat, and that heat in its transmission sets up an E M F wherever it crosses a junction of two dissimilar molecular conditions, the direction and the degree of this E M F depending on the specific properties and conditions of the substances, § 606.

1389. *Molecular differences* underlie the action, for *any molecular change* will set it up. Thus, it will occur in a single wire, if a portion is filed away so as to make a great difference in the heat capacity of the metal in the two directions; a stress upon a part in excess of the elastic limit, or hardening in the case of steel, makes the two parts act like different metals. Or if a hot wire be put in contact with a cold one of the same metal it is found to be positive, because the heat suddenly passes over to the cold wire.

Two pieces of the same iron wire will form a couple if one of them is magnetized by a helix. Even the difference of arrangement caused by rolling metal into sheets is effectual: a piece cut L shape, one arm with the grain and the other across it, constitutes a thermo-electric couple.

1390. The metals which differ must in this respect have other important distinctions. Thus, M. Joubin has shown ('Comptes Rendus,' February, 1891) that there is a relation to molecular volume; that metals classify themselves upon two curves, (1) in which the number of molecules per volume is proportional to the sixth root of the specific resistance, these being magnetic substances, and (2) inversely so proportional, these being diamagnetic. Curves very closely similar are derived from the thermo-electric relations, showing, as is done by so many other facts, that the molecular structure of matter is the real cause of phenomena, to explain which, properties of the ether are so readily manufactured.

1391. The +, or *positive* metal or substance, is that whence a current passes across the heated junction within the system. This corresponds to the zinc in a battery. The E M F depends (1) on the specific substances, (2) on the difference of temperature at the two junctions, taking as a type the simple unit element of two wires, say iron and German silver soldered together at both ends, and the heat applied at one junction: intermediate junctions do not affect the result, because they neutralize each other. Thus, either the iron or the German silver wire may be cut and joined to a copper wire forming a galvanometer circuit, without affecting the E M F.

1392. The *absolute mean temperature* of the two junctions varies the E M F for a given difference of temperature, and even its direction; thus, near 300° C. copper and iron are neutral, but below that copper is + to iron, and above it iron is + to copper. This change appears to occur at a "critical point," at which softening or some molecular rearrangement occurs. The Peltier and Thomson effects reverse in like manner at special temperatures.

1393. The following figures show the E M F of various metals with lead near the ordinary temperatures, calculated by Jenkin from Matthiessen's experiments. The value is in micro-volts per degree Cent. :—

Bismouth pressed wire ..	+97·	Silver	- 3·
" crystal axial ..	65·	Zinc pressed wire	- 3·
" " equatorial	45·	Antimony, pressed	- 6·
German silver	11·75	Iron, piano wire	- 17·5
Lead	0·	Antimony, axial	- 22·6
Copper, commercial	- 1·	" equatorial ..	- 26·4
Platinum	- 0·9	Selenium	- 807

Under like circumstances Clark obtained from:

Copper and iron. ..	Volts	·0006	Antimony and bismuth ..	·0051
Platinum " ..	"	·0011	Clamond's alloy and iron ..	·0102
German silver and iron	"	·0020		

1394. Some alloys are found most powerful, especially after frequent meltings. Marcus used a German silver as + metal composed of 10 copper, 6 zinc, and 6 nickel, and for − metal an alloy of 12 antimony, 5 zinc, and 5 bismuth, and other alloys are used, but it is obvious that alloys must be subject to steady deterioration by the heat, and a breaking down of their structure, such as occurs spontaneously with brass.

Galena, sulphide of lead, and *pyrites*, sulphide of copper, have been used as materials for piles, as also other non-metallic conductors.

1395. *Thomson effect.*—If a wire is heated at one spot, the heat will extend to equal distances on each side; if current is passed this equality will be disturbed, and the heat will extend further on one side. In copper the current, as it were, drives the heat before it, in iron it draws the heat towards it. Some speak of this as the "specific heat of electricity," which they say is + in copper and − in iron; but this is a phrase without meaning. The action itself serves to measure the thermo-electric capacity of a substance, and because it is *nil* in lead, that metal serves as the datum of comparison.

The quantity of heat carried by the current is proportional to the current strength, the absolute temperature and a constant for each metal:

Cadmium	$3·678 \times 10^{-8}$
Antimony	$-7·081$ "
Bismuth	$-3·909$ "
German Silver	$2·560$ "

1396. *Peltier effect.*—A current passing across a junction of two dissimilar metals absorbs heat (that is, cools the junctions) if it passes in the direction of the current which heat would produce. If it passes in the opposite direction it produces heat, in excess of that due to the resistance. There is an evident analogy here to Lenz's law, § 950, and a further evidence of the dependence of the phenomena upon molecular conditions and actions.

1397. THERMO-ELECTRIC PILES.—For scientific purposes these are usually made of bismuth and antimony, because these give the highest E M F; the metals are cast as small square rods, with lugs on the ends for connecting together.

In all cases the edges should be carefully united with solder suited to the temperature to be used. For large piles, especially when high temperatures are to be used, a plate of metal should be interposed to act as collector of the heat on one end, and as radiator on the other; copper is best, as a good conductor, where the heat is not too great; on the cooling end it should be painted with lampblack and size. These collecting plates or rods can be exposed to direct heat which would ruin the elements, and might be built into the walls for the purposes indicated, § 1387.

Dr. Gore described a pile made of German silver wire ·7 mm. and iron wire ·55 mm. mounted on a frame so that the ends dip on one side into melted paraffin, and on the other into non-volatile petroleum or thin machinery-oil contained in troughs. He finds with 295 pairs and a difference of 130° C. an E M F of 1·005 Volt or ·000062 per pair per degree C. which is suitable for measuring E M F.

The combination of German silver and iron, though not powerful, is a very convenient one, not apt to get speedily out of order.

1398. *Clamond's pile* excited great expectations some years ago. He used iron for + element in the form of sheet tin bent into a cup with an inward projection or dovetail. The – element was a bar 2–3 inches long, and $\frac{3}{8}$ by 1 inch in width, of two parts antimony and one of zinc; these were cast in a mould containing a sheet iron cup at each end, with projections for uniting the parts together. These were mounted in circles, and again ranged to suitable height, the whole being bound together and insulated with powdered asbestos and soluble glass. The heat was applied in the tube thus formed, with a protecting cylinder of fire clay, between which and the face of the elements the heated products were drawn downwards by a flue.

1399. *Noe's pile*, though less ambitious than Clamond's is much used in Germany for laboratory purposes, to replace batteries: it is made of German silver and zinc antimony. The end of the – bar is cast into a cup of brass or German silver, into which a German silver wire enters, as also a projecting copper rod: twenty such pairs are arranged in a horizontal circle with these rods pointing to the centre, so as to receive the heat of a Bunsen burner, which they carry to the end of the element. The outer end of the bar is soldered to a plate of copper terminating in a cylinder of the height of the instrument, up which a stream of air is drawn to cool the outer junctions. The – bars are about 1 inch by $\frac{1}{4}$ inch in dimensions, about ·025 ohms resistance, and give about ·0666 Volt E M F.

1400. *Gulcher's pile* is the latest candidate for favour: it is composed of tubes of pure nickel, in which a small gas-jet burns, and rods of an antimony alloy: it is claimed that a set of 50 couples gives 4 volts with an internal resistance of ·5 ohm, with a consumption of 8 cubic feet of gas per hour; this may be considered as equivalent to a current of 4 ampères in an external circuit of ·5 ohm.

1401. *Efficiency of Thermo-piles.*—If we take these figures and reduce them to the terms of cost per unit, § 1103, we have $4^2 \times \cdot 5 = 8$ Joules or practically 1 cubic foot of gas per Watt hour, which is 1000 cubic feet per B O T unit, or a cost of 3*s.*, which is to be compared with the cost by batteries, § 1110.

It is stated by experimenters that the average consumption of gas in good thermo-piles is 105 cubic feet per kilo-watt hour, which is the B O T unit, while that of electric current from a gas engine at 21 feet per H.P. hour and a dynamo efficiency of 85 per cent. would be 35 cubic feet.

1402. *Thermo-piles have their practical use*, therefore, as convenient substitutes for batteries in private use, because, apart from questions of cost, they get rid of the trouble and attention. As thermo-piles are probably injured more by heating and cooling than by work, many might find it advantageous to keep one constantly in action, charging accumulators, and use these in place of the more troublesome batteries.

Their drawback is the tendency to get out of order and break down.

1403. Their *low efficiency as converters* of energy is due to their ready dissipation of heat by conduction in the masses of the metal, so that only a small proportion of the heat energy supplied is taken up in the piles, as in other cases of combustion, and of this only a small part is converted into electric energy and sent into the circuit.

1404. CONSERVATION OF ELECTRICITY.—This is an idea set forth about the same time by Prof. S. Thompson and M. Lippmann, but with some differences. M. Lippmann embodies well-known facts in a mathematical formula, and Prof. Thompson says the doctrine "teaches that we can neither create nor destroy electricity, though we may alter its distribution." The doctrine appears to have no real meaning at all, and is only intelligible if we consider electricity to be an actual entity or fluid; in that case it is of course indestructible, like matter and energy. All the facts connected to the doctrine are equally consistent with the conception of electricity as a molecular action of energy, because the molecular or equivalent constitution of matter is itself unchanged, and the "quantitative" molecular action which is known as "electric quantity" is also definite, and must therefore remain constant through all the changes of electric action.

1405. Electric Welding.—This process which promises to become of great importance in the arts, originated in the observation by Professor Elihu Thomson of the joining together of two wire ends in some of his experiments. There are now two modes in use which act in entirely different manners, the direct current, and the arc, and each has its special fitnesses. The special feature of the direct, the Thomson process, is that the heat is generated *from within the metal*, which is therefore not liable to be burnt; the heat is also most strongly generated at the parts which are imperfectly united, that is, where it is most wanted. The process consists in fixing the two ends in massive clamps, which are arranged to press towards each other, and so squeeze the metal together, as it softens; this *upsets* the grain, as the blacksmiths call it, and causes a local thickening, which, where possible, is hammered down to the regular size, and in other cases, turned or filed down.

The clamps are the terminals of the conductor carrying the current; this may be a direct one from a dynamo or secondary battery, but is more usually and conveniently an alternating one from a transformer. The currents are very large, but only one or two volts are needed: the ampères depend on the nature of the metal and its area: 1 inch round iron taking 5000 ampères for 40 seconds, and 2 inch 20,000 ampères for 80 seconds, the power consumed being about 7 H.P. per ½ inch square of section. It is best to make the ends slightly conical, so as to begin the work in the middle and make the joint without much pressing out of the metal.

1406. All the metals and alloys can be welded with proper precautions not only to themselves, but to others, though of course the more perfectly, the more nearly alike their softening points. Professor Thomson exhibited at Paris in 1889, a bar ⅜ths of an inch, made up of nine metals—copper, brass, iron, German silver, brass, tin, zinc, tin and lead. Brass is commonly joined to iron, and even cast-iron can be welded. The strengths of the welds are found to be over 90 per cent. of that of the metal bars.

1407. This process is not readily applicable to closed objects, as the current would pass the other way round, though it is possible that this may be got over with alternating currents by "choking" this other circuit, by means of inductance. But links of chains have been made, and could easily be made, with two joints butted together, instead of one weld as usual, and possibly cylinders for steam boilers might be similarly made.

1408. ARC WELDING.—This was introduced by Dr. Bernardo, who connected the two surfaces of the metal to the − conductor of a secondary battery, and an arc carbon to the + terminal: the object is to avoid the burning of the metal which is enveloped in the carbon vapour. This process is, of course, practically identical with the well known process of "lead burning," the heat travelling along the line of junction, and if necessary, fragments of the metal worked into the openings. This has the great advantage of enabling repairs to be effected to machinery, &c., *in situ* in many cases. It is, however, doubtful whether the metal is of perfect quality, the heat being externally applied and not adjusting itself spontaneously to the requirements as in the other case.

Messrs. Lloyd & Lloyd, of Halesowen, have applied this process largely in making welded pipes, but they reverse the direction of the current mentioned, finding that with the iron as + longer arcs are obtainable. They also use the arc to replace the shearing and chipping processes, and cut iron into any desired shape, the arc melting out a line of metal at a quick rate, and serving many other purposes to more advantage than fire heat: they follow the arc up with the hammer (sometimes electrically worked), as the metal simply run together is crystalline. They use large secondary batteries of the Planté type, as these stand sudden calls for large current delivery better than the pasted cells.

1409. THE HERTZ RADIATIONS.—These have played a great part in recent theoretical discussions, and though space will permit only a slight description, this may assist readers in getting some clear ideas about what is usually buried in mathematical formulæ and pure hypotheses. To get away from these it is absolutely necessary to fix the mind upon *each separate point in* turn, § 1414.

1410. The apparatus consists of two parts, 1 the source, the vibrator or oscillator, 2 the receiver or resonator, and it should be realized that this last name *assumes* the explanation of the action. The *source* or oscillator is a condenser, or circuit having inductance, and an opening or "spark gap": the true source is, however, an induction coil sending successive charges into the condenser, and this latter, by "surging," converts each coil spark or charge into a succession of to and fro oscillations, the rate of which depends on the capacity of the condenser, §§ 524 and 916: each oscillation therefore implies a to and fro sway of the di-electric, i.e. undulation in its substance.

1411. The resonator is of varied form; it was at first a circle of wire with a spark gap, but is usually a condenser, consisting, like the vibrator, of two metallic surfaces hanging in the same plane, the two pairs facing each other, § 512. Whatever the form, it is necessary that the two apparatus should be tuned together; in other words, they should have equal capacities, and, where wires are involved, their lengths, &c., must be related to each other, and to the rate of vibration set up.

1412. Dr. O. Lodge's apparatus is on the same principles. He uses two similar Leyden jars with similar wire circuits to each. 1, The "oscillator," is connected to the coil and a wire circuit from the outer coating to a "spark-gap" at the knob of the inner coating: 2, the "resonator" is a jar of the same size, fitted with a wire circuit of two wires, with a cross wire which can be moved about in order to "tune" the circuits, or in other words, to equalize their conditions: when thus tuned, and then only, sparks in the *secondary* or induced circuit accompany those at the *primary* jar.

1413. All these arrangements, whatever may be the case as to the results, are purely our old well known apparatus for induction, and this is clearly shown in the latest form of apparatus used in the most recent and interesting researches of M. Blondlot. He uses a vibrator consisting of two semicircular wires, with a spark-gap at the points connected to the coil, and a pair of condenser plates connected to the ends at the other side of the circle, these plates being movable in order to vary the capacity: the resonator is a circle of wire laid near to and parallel to the vibrator, but opened at the point over the primary spark gap, and extended there into two long parallel wires, with a shifting bridge, just as in that of Dr. Lodge. By this means the so-called "rate of undulation" can be measured, or in other words, the rate of propagation in the wire, *not of electric undulations* as is asserted, but of the successive impulses imparted to the molecules of the circuit.

1414. Here we may see the importance of *isolating each fact*, § 1409; we are dealing with a series of phenomena, a succession of + and − impulses: we call this an alternating current in some cases, but when we go down to the foundation of *fact*, we find that we are dealing with merely the conditions of the commencing and ending of successive currents of infinitesimal duration; it is estimated that the period of the Hertz undulations is $\frac{1}{300000000}$th of a second: none the less, each is really *a current*; the facts of each separate undulation are those of § 496 and Fig. 59.

1415. The action at the vibrator is called a "radiation" transmitted across space, as with light, to the oscillator. But what is meant by this word "radiation"? Is what happens there different from what happens in every condenser? Is it not, first, the production of lines of force—not from vibrator to oscillator—but between the two plates of the vibrator itself, a condition of "charge" of the primary condenser?

That is the first fact to be isolated, in accordance with all our knowledge. The action crosses space, and it may be taken as proved that it does so, as it also traverses wires, § 120, at the speed of light: it may be by the ether or by air, it does not concern us now; we want to understand now what "radiation" means. We know how the radiation of the light of the spark crosses that space; it travels outwards in all directions in straight lines. We know that the two plates of the condenser are in different electric conditions, + and −: is the radiation twofold? and if so, what keeps the two from joining? Is it a single quality, a commencing undulation purely, such as light certainly is? if so, what is the relative function of, and need for the two condenser plates? Let us seek the answer in known facts.

1416. This impulse is merely the commencement of a current, § 1414: what would happen if the current were continued? the immediate extension into space, not of rays *from* the plates, but of curved lines between the plates: the case is studied § 122, Fig. 24, and is strictly analogous to the setting up of the magnetic field, § 954, Fig. 77. We may say, however, that it is easy to conceive a sustained stress spreading outwards into space, and yet ask what causes a stress, which has ceased, to continue still to travel onwards, why do the lines expand, and so reach the oscillator? Is it a fact that they do so *before the stress ceases?* The action travels many feet, a good deal further than experiment has tested in the period of an oscillation. But there are other explanations to be considered.

1417. When we throw the stone into the pond, § 1165, we see an expanding circular wave formed, which we might compare to the expanding curved line of force; we should be wrong, because the continuous circular wave is not a reality, there is no relation between its parts; the true action here is *radial*, the apparent circle only results from the radial independent actions being equal at all parts, because in one medium. But we know that an electrical impulse can and does travel after the impressed force ceases: it does so in cables, § 506: is there any reason to suppose a line of force can similarly travel onwards, as the water wave appears to do? is there anything to replace the radial impulse of the stone? We can find this in the circular magnetic field which surrounds every electric line of force; we might find it in that *momentum* which must accompany electric propagation if it is connected with molecular motion. But this would take too much space to follow up; here it is enough to show that the doctrine of propagation by radiation is a mere hypothesis and is not necessary, while opposed to the known facts of electricity.

1418. The point of moment here is that the actual facts, the experimental results relate wholly to the propagation of a disturbance artificially produced, to a motion which is of necessity undulatory in form, because it is rythmically generated from successive distinct impulses. The hypothetical explanations are applied entirely to the nature of the transmission of electric action itself, with which the experiments have no more to do than the mechanically set up undulations in a rope have to do with the nature of the nervous power which originated the impulses, § 887.

1419. The real interest of the Hertz experiments is in his discovery that the impulses could be reflected and refracted, as light and sound can, and travel in planes which permit their polarization, a circumstance which in itself shows that they are not rays, but lines which can pass through wire screens when parallel to them, while they are stopped if they cross. He showed that the undulations travelling outwards, can traverse non-conductors, but when falling upon a metal sheet are reflected, and then act just like the water wave when it reaches the edge of the pond and returns upon itself: in this way he was able to locate points of intersection, nodes, fixed places of maximum and minimum action, where the resonator would act or cease to act, just like the crossing of the waves in water; but they differ in this respect, that these so called electric *waves* have no existence: one electric impulse complete in itself, § 1414, moving outwards and being reflected, meets an altogether newly originated electric impulse which in this kind of experiment is rythmic, and produces apparent waves simply because the molecular impulses, while each independent, are made—mechanically, to follow each other at regular intervals.

1420. ELECTRO-MAGNETIC REPULSION.—Some of the phenomena of alternating currents and their magnetic fields, which are of great interest and probable future practical value, were brought into notice by Professor Elihu Thomson, and a full account is given in a paper read to the Society of Arts by Professor Fleming, 14th May, 1890. The most striking experiments show an apparent repulsion by which masses of copper are kept floating in the air, but which is the result of the inter-action of electric currents. Thus a copper ring will rise above the magnet, and remain there, held down by cords. A still more striking illustration, more easily shown by ordinary appliances, consists of a coil of insulated wire attached to an incandescent lamp and placed in a glass vessel containing water, and standing over the magnetic pole: current induced in the coil manifests itself in two ways; 1, it lights the lamp; 2, the lamp and coil, if weight and force are adjusted, rise and float in the water.

1421. The force generated is proportional to the mean square of the current, § 431, that is, to the current energy: but the effect depends upon the conductance of the induced substance: thus it can be weighed by discs of different metals of equal size and thickness suspended to a balance over the pole, when the result is proportioned to the conductivities of the different metals, so that this action would at once distinguish a silver coin from a bad one. Also a radial cut in the disc or non-completion of circuit in a wire prevents the effect, as does the interposition of a metallic screen.

Rotation is produced in pivoted discs when a conductor is partly interposed between them and the pole so as to intercept part of the lines of force and set up differential attractions.

1422. There is no real *repulsion*; the apparent repellent action is like others which have been studied, a differential relation between two opposing fields. These phenomena are indeed the long known actions of electro-magnetism, the slow falling of a metal disc rotating in a field, but modified by the rapid reversals of the field and current: we have the effects, not of continuous current, but those of beginning and ending currents, as in § 1414.

1423. When a closed ring of wire is held in face of an electro-magnet pole, with the turns parallel in both, it is subject to two actions: 1, the induction of the primary, or magnet coils, acting upon it as a secondary circuit; 2, the lines of force of the magnet traverse the coil and act on its wire, just as a bar-magnet entering them would. Both actions tend to set up a momentary current opposed to that of the electro-magnet, which is in fact an opposing E M F to the E M F or inductive force of the primary, § 950; as these conflict there is an apparent *repulsion*, the coil would, if free, give a swing from the pole outwards, as though it followed the stream of energy issuing from the magnet. At break of circuit the reverse action occurs: the induced coil is thus subject to alternate impulses, and if the "frequency" of these impulses, were adjusted to the "time of swing" of the coil, regarded as a pendulum, a regular and growing vibration would be set up.

1424. But cause and effect can never be synchronous: the cause must precede the effect: hence the inducing E M F rises somewhat in advance of the curve of the induced current set up, or as it is more commonly stated, the current *lags* behind the E M F; their *phases*, the crests of their waves differ. But the result is that the induced current of one impulse somewhat overlaps the *next* inducing impulse of the primary, and the effect of this is to diminish the period of the attracting actions, and prolong those of the opposing ones, and thus to change the to and fro swing into a constant, or rather a prevailing tendency outwards from the magnet—apparent repulsion.

1425. The effect of interposing a metallic screen is thus comprehensible: it absorbs the inducing energy in itself; currents form in it, and rapidly heat it: it in fact plays exactly the part of the sliding tube in the coil, § 1150.

1426. TESLA'S EXPERIMENTS.—The speciality of these, as differing from the familiar induction coil experiments, is best described in his own words ('Journal of the Institution of Electrical Engineers,' April 1892): "We operate the coil either from a specially constructed alternator capable of giving many thousands of reversals of current per second; or by disruptively discharging a condenser through the primary, we set up a vibration in the secondary circuit of a frequency of many hundred thousands or millions per second." Instead of a direct current interrupted at most a few hundred times a second by the break, we have alternating currents either produced very rapidly or set up by "oscillations," § 1410.

1427. Instead of the ordinary lightning-like discharge of the coil or machine spark, a prolonged brush discharge is obtained, filling the space between two parallel wires forming the terminals.

When two such fine wires, many feet long, are employed, very interesting effects are produced: they can be used separately; M. Tesla distributed them each upon a frame, so as to build up the words William — Thomson, when the two were illuminated, to all appearance independently of each other; there are in fact many experiments which *appear* to indicate the separate manifestation of + and − conditions. But we may be sure that this is only apparent, a connection across the intervening space does exist, and it becomes manifest when the two wires are stretched out parallel and near to each other; then they glow in their whole length with manifest action on the intervening space, and with evidence of the separate actions of each impulse, producing waves in the wires as in § 1413.

1428. In some partially exhausted bulbs, with one terminal attached, a rotating brush discharge is set up, which is wonderfully sensitive to magnetism, the direction of rotation being due to the lines of the earth's field, and the cause of rotation itself being that explained, § 1424, a differentiation in the duration or strength of the alternate impulses; the brush rotating for causes similar to those which cause discs to do so in the magnetic field.

1429. Many interesting experiments were made combining Crooke's vacua and phosphorescent bulbs with these electric actions, all of which fully confirm the statements of § 1181, that the light giving vibrations are not "electric undulations," but molecular or atomic *vibrations in matter*, the mechanical results of the electric disturbances. And this is the teaching of every *fact* in electricity, that it is a function of matter, of matter under stresses, distributing energy.

1430. SWINBURNE'S *high tension experiments* at the Crystal Palace have a special interest, in that, working with 130,000 volts, the apparatus was of the ordinary commercial type. The 2000 volts of a Mordey alternator were transformed down to 150 volts, at which the manipulations were easily and comfortably managed. Hedgehog transformers in oil insulation, § 1160, then raised the voltage to the desired point.

Vacuum tubes, with no closed circuit, but hanging from a wire over a sheet of tin-foil, acting as a condenser, were illuminated as in § 1182. A space of 6 inches between two fine wires was traversed by the sparks: when an arc was formed between two copper hemispheres of 4 inch diameter, it rose in a curve.

Glass plates were pierced, and the usual classification of insulators shown to be only comparative by the use of slate pencils in place of carbon in the arc lamp, while a strip of wood first shewed sparks at various parts of its length and then broke into flame.

1431. Mr. Swinburne estimates that 2 H.P. could be transmitted to a motor through a man's body without injury, but that is an estimate which may not be very soon translated into fact: he also estimates that 50 H.P. may be transmitted at 13,000 volts (see § 1115) from Niagara to London over a No. 12 wire with a loss of only 2 H.P.: but in this calculation impedance is probably not allowed for, and certainly the wire would not be enclosed in a cable.

1432. It may be mentioned that the curved arc has been converted in Mr. Siemens experiments into a pair of nearly vertical columns united in a mass of flame at a height of 3 to 4 inches, so approximating to the very remarkable experiments with magnets in which the arc has been divided into two vertical flames apparently disconnected, an effect resulting from the mutual reactions of very rapidly following impulses within a magnetic field.

1433. These experiments indicate that an entirely new field of research is being opened out, and new aspects of the structure of matter and the operations of its ultimate particles presented to us. But this differs from our old electrical studies in one very important respect; the electrical student could with a few simple apparatus which he could make for himself from cheap materials, follow out the most important and interesting studies, and hope to make discoveries for himself: this new field must be reserved for those possessed of costly apparatus, and with powerful sources of energy at their command. The work will be done only by Institutions provided with complete physical laboratories for investigation and teaching, or else by those who can afford to spend much in the hope of discovering something commercially profitable.

1434. But already they are showing how inconsistent with facts is the etherial and external theory of transmission of electric energy from the source to the point of expenditure. Everywhere we find the energy led by a closed circuit between the two poles of the source: everywhere we find it transferred to a second circuit, electrically closed either conductively or inductively, and always by the agency of the predetermined magnetic field produced by the primary circuit, as explained in the chapter on Current, §§ 466–7, &c. In no single case has any fact been brought to show the transmission of energy *from the source itself;* or from the conductor even, except by the changes in the magnetic field of the primary conductor, effected by that reversal of polarity which every theory bases upon, and every fact proves to be, a changed order of arrangement of the particles of matter.

CHAPTER XV.

DICTIONARY OF TERMS.

THIS chapter is intended to supply concise definitions of terms for occasional reference or to recall their full explanation to the mind, but in some cases information is given on subjects not noticed in the other parts of the book.

Absolute, see Units.

ACCUMULATOR.—Another name for secondary batteries.

AGONIC LINES.—Lines running through those parts of the earth in which the terrestrial and magnetic meridians coincide: i.e. where there is no variation.

AMALGAMATION.—Zinc is protected from waste by having its surface coated with mercury. For the process with zinc, see § 184; for other metals, § 743.

AMPÈRE.—The B.A. unit of current, see § 422.

AMPLITUDE.—The extent of swing, as in a pendulum, or the *height* of wave-motion; the strength of wave-action, as the loudness of sound, depends on this, while the character, as pitch of note, depends on wave-*length* or time.

ANION.—The electro-negative, acid, or chlorous radical of the salt or acid decomposed. Oxygen, acid radicals, as chlorine are anions (see Ions).

ANODE.—The positive electrode or plate of a cell; the wire or plate connected to the copper or negative element of the battery; the plate which leads the + current into a solution to be decomposed, and at which are set free the oxygen, and all − ions (anions). In electro-metallurgy it is usually formed of the metal to be deposited.

ARC.—The air space in which the electric light forms; it contains carbon vapour and gives off the violet rays which render the arc light so steely in character.

Arc, see Multiple.

ARMATURE.—The keeper of a magnet. *Armature of dynamo machine:* the part which, like the *keeper*, closes the magnetic lines of the field magnet; it is usually the moving part.

ASTATIC.—Without inherent directive power; usually applied to pairs of reversed needles, § 341.

ATOM.—The supposed ultimate particle of the elements, p 2.

There is still much confusion as to the terms atom and equivalent, which were formerly used for the same purpose, but modern chemistry attaches a distinct idea to the atom, which correlates it, not only to chemical affinity, but to heat and other forces.

ATOMIC WEIGHT.—The relative weights of the atoms as compared with that of hydrogen taken as 1. At p. 308 is a table of the atomic weights and other particulars of the elements most important in electricity.

BALANCE.—See Bridge. *Hughes' Induction*, see § 1384.

BASE.—See Radical.

BATTERY.—A combination of voltaic cells. The word is commonly—but erroneously—used for a single cell (e.g. Smee's battery), but it strictly means two or more cells coupled together in series. The term is also applied to similar combinations of Leyden jars.

BREAK.—See Commutator.

BRIDGE.—Wheatstone's. An apparatus for measuring resistances by balancing the unknown R against one known and capable of regulation, § 440.

B.A.—British Association. See Units.

B.O.T.—Board of Trade unit. Others use the letters B.T.U. See §§ 428 and 1104. The Board gave the name of "Kelvin" to this unit, but withdrew it.

BRUSHES of *dynamo machines:* the collectors of the current.

CALORIMETER.—Instruments for measuring the *quantity* of heat produced; thermometers measure the temperature or *intensity* of heat, § 386.

CALORY.—The heat unit of the metric system, see Therm, and § 426.

CANDLE, *Electric.* An arc light generated at the end of two carbon rods arranged side by side, and burning away equally. First made by Jablohkoff.

Candle-power of light.—The legal standard for measurement of gas is a spermaceti candle of six to the pound burning at the rate of 2 grains per minute.

CAPACITY.—The power of a surface or dielectric arranged as a condenser to hold a "static charge." Its unit is the farad.

CASCADE, *charging in*, is the old term for Leyden jars arranged in *series*, like voltaic batteries.

CATHODE.—The negative plate of a cell; the wire or plate connected to the zinc; the plate at which, in any decomposition cell, the cations or + ions are set free. In electro-metallurgy, the object upon which the deposit is to be formed is the cathode.

Cation.—Electro-positive elements and radicals, which are set free in electrolysis at the cathode. Hydrogen and metals in the order of the electric series are cations. See Ions.

Cell.—Each separate vessel in which a chemical action occurs forming part of the electric circuit. Thus there are the active or generating cells—i.e. those which form the battery, and the decomposition cells, and these last may be of two classes: (1) Passive or mere resistances, such are those employed in electro-metallurgy where the metal is dissolved from the anode, and simply transferred to the cathode; (2) where chemical force is exerted and absorbed in effecting true decomposition, as in the gas voltameter.

C.G.S.—Centimetre Gramme Second See Units.

Charge.—The measured quantity of static electricity accumulated on a conductor or a condenser.

Chemic.—See Current, Units of.

Chlorous.—Pole, a term sometimes used for the negative pole, or cathode. A chlorous radical is that radical of a salt or acid which answers to chlorine in HCl—that is, it is the acid radical or electro-negative element or anion

Choking Coils.—These are used with intermittent currents, to produce the effects of a resistance which does not expend energy; that is to say, their inductance sets up an opposing E M F which resists that from the source and diminishes the rate of current flow. The simplest type is a closed coil C surrounding an iron core magnetized by another coil M. The coil C now produces *magnetic retardation* in the core, just as the core produces electric retardation in a circuit: the magnetism cannot pass along the core, beyond the coil, until the coil C has taken toll of the energy and set up current in itself. They will probably find many uses.

Circuit.—The path along which the current travels, or in which electric tension is set up.

Conductive circuits are those through which current passes, and are composed wholly of conducting materials.

Inductive circuits apply to static electricity, and are partly composed of insulating materials as air or condensers.

We may conceive a conductive circuit as represented by an endless chain driven by a drum to which force is applied (this representing the generator); such a chain will drive any machinery to which it is connected, as the current does work. The inductive circuit resembles more a single chain acting on a spring, like a bell-wire, so that only single impulses can be given, and on release the spring restores the energy.

Derived circuits are a division of the path in two or more parallel branches.

CIRCUIT, *magnetic*, the path of the lines of magnetic force, composed of the iron or steel and the external field. The conception is analogous to that of the electric circuit, but though useful, tends to mislead, see § 958.

COMMUTATOR. — Break, contact-breaker, circuit-changer, or switch. They are of many forms according to the purpose required; a simple spring pressing on a point serves for a mere break or interrupter of the current, but the arrangement is often complicated when it is necessary to provide several different circuits for the current.

CONDUCTANCE. — The conducting capacity of a circuit: the reciprocal of resistance.

CONDUCTIVITY.—The specific capacity of any substance to transmit current: the *conductance* of unit dimensions of the substance.

CONDUCTOR, *prime*.—The terminal of frictional machines.

CONDUCTORS.—Substances which permit electricity to pass. It used to be thought that substances were of two distinct classes, conductors and insulators; but it is now known that it is only a question of degree of resistance. Silver is the best conductor, then other pure metals, then alloys; solutions of electrolytes follow but at a long interval. Current passes through conductors in the ratio of their sectional area, and the inverse ratio of their length.

CONNECTIONS.—Wires, &c., completing the circuit between different apparatus; they should be sufficiently large, and of copper so as to give little resistance. There is often much trouble caused by the stiffness of stout wires, it is therefore well to form a spiral upon each connection, so as to give a little elasticity. The best connections, however, are made of wire cord, such as is made for window sash-line, or by twisting up fine copper wire into a cord; lengths suited to various purposes should be cut, and to the ends should be soldered pieces of No. 12 copper wire, of a couple of inches long, for insertion in binding-screws. If these ends are well silvered or gilt, much trouble in cleaning will be saved. Annoyance from accidental contacts, &c., is also avoided by covering these conductors with narrow tape plaited on, and soaking with boiled oil.

For *uniting wires*, blocks of brass are useful with two parallel holes drilled through and a screw to press in each. A simple connection may be made with a piece of 18 copper wire 3 inches long, hammered flat for 2½ inches and filed smooth so as to give it spring: it may then be tinned with a soldering iron, or preferably nickelled or gilt, and then wound up in a helix upon a piece of iron wire larger than any wires it is to be used with:

it can be then curved so as to grasp a wire end pushed into it. Two of these joined together or made on the ends of one piece make a perfect connection; they can be joined in any number.

Wood-screws make convenient connections if a piece of wire is soldered in the cut, to turn them with; a piece of sheet metal with a wire attached to it may be placed in the hole in which they work, and a metal washer under the head to grip a bent wire placed under it.

Binding-screws and fittings are now cheap and easily obtainable, and students supplied with the fittings of modern classrooms may be apt to look down upon make-shift appliances; but by such make-shifts the science of electricity has been created, and many an earnest student with limited funds will not only find them useful, but learn more in devising and making them than if he were supplied with the most perfect instruments.

CONSEQUENT POLES.—Where, intentionally or accidentally, two N or two S poles are formed together S—N N—S, producing, apparently, a magnet with similar poles at each end.

CONSTANT.—A value which correlates individual cases to general laws. The constant of a galvanometer is the value in ampères corresponding to unit deflection; or it may be the resistance which, with a given battery, produces unit deflection.

COULOMB.—The B.A. unit of quantity, which passes in 1 second of an ampère current.

CURRENT.—This word is used in many ways. The electric current means the supposed flow or passage of electricity or electrical force in the direction from + to – or positive to negative. It therefore originates at the zinc surface in contact with the solution, and passes from the zinc to the copper or other negative metal *in the liquid* of the battery, but *from* the negative metal to the zinc in the external circuit (see Positive and Negative). *Current* also means, scientifically, the measured work done chemically, or what was formerly called "Quantity" (which see, also Intensity of Current). For the laws governing this, see Ohm's Laws and Units. See Density.

Current, Units of.—The accepted B.A. unit is the *ampère*, which is the result of 1 volt of electromotive force acting in a circuit of 1 ohm resistance. Its chemical value is given, § 422. At first it was called the "Veber."

The *Chemic* is used in these pages where it is desirable to keep in view the relation of electricity to atoms and molecules of matter, which it does more perfectly than the ampère, as explained, p. 206. It represents one grain equivalent of chemical action in 10 hours.

Declination.—The angular difference, at any part of the earth, between the nearest pole of the earth and the corresponding magnetic pole: it is the *variation of the compass*.

Density.—The "quantity" upon unit area of surface, which varies on the one surface according to form and nearness of surroundings.

Density of current, its ratio to the sectional area of the circuit, which in the case of electrolysis, materially affects the action and the quality of deposit. Heat in wires is also proportionate to the ratio of current and section of the conductor.

Diaphragm.—A porous division between two liquids, through which electric current passes, and in which osmose occurs; and an E M F is produced as a result of capillary actions.

The vibrating disc of telephones.

Dielectrics.—Non-conductors in which induction occurs, such as air and guttapercha.

Dynamometer.—This means "force-measure," and is the proper name for an apparatus which measures mechanical power, such as that exerted by a rotating shaft or a belt. It is often, but wrongly, applied to Weber's galvanometer, which consisted of coils, in place of needles, suspended within other circular coils.

Dyne.—The C.G.S. unit of *Force*, that which gives a velocity of 1 centimetre per second to 1 gramme weight, after acting for 1 second.

Earth.—Name derived from the old mistaken notion that electricity is pumped up from the earth as a great reservoir; *Putting to earth* and *earth connection* mean a general return circuit, which, for economy, is formed through the earth by means of "earth" plates, buried in moist strata at the various necessary points. But any conductor common to several circuits is technically called "earth."

Electrodes.—Faraday's term for the poles or plates leading the current into and out of a cell. See Poles, Anode, and Cathode.

Electrolysis.—The act of decomposition by an electric current, while passing through a liquid.

Secondary electrolysis is supposed to be effected by the chemical action of the substance really set free by the current (see Nascent). For explanation of this action, see § 694.

Electrolytes.—Bodies capable of being decomposed by an electric current. They must be composed of (or rather be capable of breaking up into) two radicals (see Ions); therefore substances which contain three or more radicals are not electrolytes.

Electrometer. — Instrument for measuring electrostatic charge, or tension.

E M F or Electromotive Force.—The tendency to set up electric current: in galvanic batteries the E M F is set up by the attraction of zinc for an acid radical. It may be either continuous or intermittent. Galvanic batteries and frictional machines set up a continuous E M F, which may be compared to a steady pressure in its actions and laws.

Moving magnets, charged condensers, the wires of induction coils, set up a variable E M F, which may be compared to the energy of impulses and with the laws of projectiles.

Electric pressure is now commonly used for E M F, as is also the term *voltage.*

The unit of E M F is the *volt.*

Elements.—The ultimate substances into which all the bodies we know can be resolved, and which, themselves, have not been resolved into any simpler bodies, see § 5.

Endosmose.—See Osmose.

Equivalents.—All chemical actions take place in a definite ratio, which is explained by the atomic theory as due to the combination of 1, 2, or more atoms of one substance or element, with 1, 2, or more atoms of others. Each element has its own equivalent weight, as compared with hydrogen as 1. There is much confusion of ideas, due to the change of modern chemistry from the old system of stating reactions in *equivalents* to the modern system of stating them in *atoms.* Table XIII., p. 308, gives a list of the equivalents. The relation of electricity to these equivalents is such, that in a chain or circuit composed of any variety of compounds of two of these bodies (which are, in fact, elements, radicals, and ions), the same current would release from combination the relative weight set against each substance, The weights themselves are relative or abstract, but in this work they are taken as "grains," for the purpose of getting a definite electric measure of current and work.

Equivolt.—A unit devised by the author to connect together energy and quantity. It is the energy engaged in affecting 1 equivalent of chemical action in a circuit of 1 ohm resistance, and under the volt electromotive force. It is described § 597. Its mechanical equivalent is 4673 foot-lbs. This unit, when thoroughly comprehended, will greatly aid in understanding electricity, and the doctrine of the correlation of forces.

Erg.—The C.G.S. unit of energy. The work of 1 dyne in 1 second. Its value is given § 410.

Erg-ten, 10,000,000,000, ten thousand million ergs, written 1×10^{10} on the index notation explained, § 411.

Extra Current.—The induced current in a wire, especially when wound in a helix, set up when circuit is broken.

Farad.—The unit of *capacity:* 1 coulomb under 1 volt.

Ferranti Effect.—A rise of voltage observed in the Deptford mains beyond that of the generators: as much as 10,000 volts were observed at London, while there were only 8500 supplied at Deptford eight miles away. Of course this is no creation of force or energy, but a redistribution of the wave form and phases, due to inductance in the circuit.

Field of Force.—The space between the poles of a magnet, or two electrically charged surfaces, and other active forces.

Galvanometer.—An instrument for measuring "current" by its magnetic effects in deflecting a magnetic needle.

Gauss.—This name has been variously used; it was applied to the magnetic field, § 149. It is now called the unit of "induction density," another form of the same concept. Its value is 10^8 "lines of force" or C G S units, see § 968.

Horse-power.—The unit of "rate of mechanical working power"; it corresponds to a supply of energy equal to 33,000 foot-lbs. per minute. The French "force-cheval" represents 32,560 foot-lbs.

Hall's Effect.—A distortion of the lines of E M F produced in the magnetic field, apparently analogous to the rotation of polarized light. But Shelford Bidwell has shown that it belongs to the thermo-electric facts and varies in different metals much as these do in the Thomson effect, § 1395. If current is passed through a strip of metal lengthwise, none will leave the strip from equipotential points at its sides (as in Wheatstone Bridge), but if the strip is in a magnetic field, and perpendicular to the lines of force, current will pass from these points.

Henry.—The new unit of Inductance, § 430.

Hysteresis.—A waste of energy in magnetizing and demagnetizing iron, owing to the inertia and frictional resistance of the particles: it appears as heat in the iron, § 972.

Impedance.—The total obstruction to conductance; resistance + inductance, in the case of intermittent currents in the variable period: it is correlated to "Retardation," § 523.

Induction.—This is the name given to effects produced outside of the body exerting a force, or out of the circuit to which the force is directly applied. Thus a magnet induces magnetism in neighbouring magnetic substances, and then attracts them.

A static charged surface is said to induce an opposite electric charge upon surfaces presented to it; as to which see § 55.

A current in a wire induces currents in other conductors parallel to it. See Secondary.

Self Induction is the misleading term for the absorbed energy which produces "extra current": it is slowly passing out of use, see § 496.

INDUCTANCE.—The absorption of energy at the commencement of current by static and magnetic stresses. Its unit is the Henry, § 430. It covers what used to be called *self* and *mutual* induction.

INDUCTORIUM.—A name for Induction Coils.

INERTIA.—A word embodying the fact that matter will neither move or stop moving, except by an external action: the resistance to change of state of rest or motion.

INFLUENCE MACHINES.—Those on the principles of the Holz, Voss, and Wimshurst types.

INSULATORS.—Bodies possessing high resistance; all, however, allow some current to escape, or rather "charge" to be lost as current. They are called "electrics," because friction develops electric excitement in them. Ebonite is the highest "non-conductor"; paraffin, sulphur, and glass follow, § 110.

Telegraphic insulators are the porcelain cups, &c., to which the wires are secured, and which prevent current leaking from the wires to the earth through the posts.

INTENSITY.—The old term for E M F. Batteries were said to be arranged for *intensity* when the cells were coupled together in series. The term leads to such confusion that it is best abandoned altogether.

Intensity of Current.—A term adopted from the French *intensité de courant.* It means "quantity"; and the best writers now use the simple word "current," to avoid the confusion of these conflicting terms.

IONS.—Faraday's term for the two parts into which an electrolyte breaks up; they may be regarded as "radicals," and may be either single atoms of elements, doubled atoms which still act as one chemically, or compound radicals, like ammonium, and the radicals of acids. They are of two classes, named from the electrode at which they appear; but it must be remembered that the same radical may be an anion at one time and a cation at another, according as it is united with a radical more or less high in the order of affinity. See Anions and Cations.

ISOCLINIC LINES.—Those drawn through places in which the dip is equal; in fact, lines of magnetic latitude.

ISOGONIC LINES.—Those drawn through places of equal *declination*, or lines of magnetic longitude.

JOULE.—The B.A. unit of energy, § 426. It is sometimes called the *joulad:* the term "joule" has also been used for the 772 foot-lbs. mechanical equivalent of heat, for which it would be most applicable.

KELVIN.—The name given, May 1892, to the B.O.T. unit, the kilo-watt. It is not actually adopted.

KNOT.—The geographical and nautical mile, which some affect to write "naut," though the name is derived from the corresponding knots on the log-line used at sea: 2029 yards.

MAGNETANCE.—A term proposed by the author, § 469, for that portion of energy which is taken up in the magnetic field, to distinguish it from "inductance" proper which should be the energy taken up in electric stresses.

MANGANIN.—A new German alloy of 12 manganese, 85 copper, and 3 nickel (manganese replacing the zinc of German silver), which is said to possess remarkable and valuable properties. Its special merit is that heat scarcely alters its resistance between 15° and 30° Cent., and *even lowers it* at higher temperatures, an effect hitherto unknown in metals. It is also soft and pliable. At date of writing it is yet unknown in England, but I am informed that it has the defect of being injured by contact with paraffin. Its specific resistance is 42 micr-ohms, per cubic cent., p. 273.

MEG-OHM.—The prefix *meg* signifies one million.

MHO.—Name suggested by Sir W. Thomson for a unit of "conductance," being "ohm" inverted.

MICRO-FARAD.—The prefix *micro* signifies one millionth. The micro-farad is the practical unit of capacity.

MOLECULE.—The ultimate particles of complete substances. Modern chemistry draws a clear distinction between atoms, equivalents, and molecules, terms as to which there was formerly much confusion. The meaning is explained, pp. 6–9.

MULTIPLE ARC.—Cells connected parallel, or as derived circuits to each other so as to act as one large cell.

NASCENT.—Substances have a much greater chemical force at the instant in which they are being set free from combination than when they are free bodies. They are then called "nascent." Most of the processes of electro-metallurgy are usually considered to be effected by secondary electrolysis, through this action of nascent hydrogen. This special energy is supposed to be owing to elements (or radicals) being then in the atomic instead of the molecular condition, and therefore having all their chemical attractions engaged in seeking a combination. It is commonly the case, also, that a radical cannot be set free at all, unless in the presence of some other bodies with which it is capable of uniting.

Negative.—In the battery, the copper, carbon, or platinum plate.

Negative Pole—Cathode, platinode.

Negative Ion.—Oxygen and acid or chlorous radicals.

Notation.—The mode of expressing chemical substances and reactions by their various symbols. Various systems are employed, § 16, but that used in these pages is the simplest known, being based upon the binary theory of salts, and showing every atom in a reaction by its distinct symbol.

Some fanciful formulæ are used for the purpose of expressing particular theories on the constitution of substances. The most prominent is Frankland's, based on the hydroxyl theory. It is exceedingly puzzling, as it does not show real atoms, but the supposed compound radicals of the theory; and as Ho and Cuo mean something different from the usual HO and CuO, it is rarely written, and never printed correctly throughout.

Occlusion.—The absorption of gases by solids, with some change of property. The union of hydrogen with palladium is the most striking instance. The absorbing power of charcoal is sometimes called occlusion, but is probably of a different character.

Ohm.—The B.A. unit of resistance. For its value see § 419.

Ohm's Laws.—These formulæ, devised by Ohm, enable us to calculate from certain data all the information we require. The symbols should represent fixed units (see Units) to obtain definite results. Otherwise they are merely comparative.

E stands for electromotive force, R for resistance, C for current. Any two of these being known we can calculate the third; thus knowing the force of the batteries to be used, and the resistance of a circuit, we can calculate the current generated, and therefore the amount of work to be effected under any given conditions.

E M F	Current.	Resistance.	Energy.
$E = C \times R$	$C = \frac{E}{R}$	$R = \frac{E}{C}$	$\left.\begin{matrix}W\\H\end{matrix}\right\} = C^2 \times R \times k$ $J = E \times C$

W means mechanical work, H is heat, k is a constant representing the suitable unit, § 426, and J the joule.

Osmose.—The process of diffusion of liquids through a porous division, which, like the diffusion of gases, shows that the molecules of matter in these states are in constant motion:

Endosmose and *exosmose* are names given to the two directions of the motion as related to any given vessel. Electric current and difference of potential give a stimulus to osmotic action, as explained § 204.

PAGE EFFECT.—The sounds produced by molecular motion in iron when magnetized and demagnetized, § 1316: it has been used in a bell push to indicate that the distant bell is acting: the push contained a small electro magnet connected to the bottom of a closed iron box, the top of which is the armature: the arrangement greatly resembling a telephone.

PELTIER EFFECT.—See § 1396.

PERMEABILITY.—Capacity for magnetism.

PERMITTANCE.—Term used for inductive capacity.

PLATINODE.—Daniell's term for the cathode or that plate in any cell which does not dissolve.

POLARIZATION.—The act of arranging the substances which form an electric circuit in a polar order or chain of + and − radicals, presented towards and reacting on each other. It resembles the arrangement which takes place in a number of magnetic needles which arrange themselves in an order of NS, NS.

Polarization of Plates.—This very confusing and absurd term is applied to an action which occurs whenever the current passes from liquid to solid conductors: there forms on the surface of the latter a film different from the liquid, by which there is not only a greater resistance introduced, but an electromotive force is generated, opposing that of the current, so that if suddenly connected to a galvanometer, and the main circuit broken, a reverse current will be maintained for some time. Secondary batteries are based on this action.

POLES.—The wires, plates, &c., leading from the battery; their name is the opposite of that of the plate they lead from; thus the zinc is the positive metal, plate, or element of the battery, but the wire leading from the zinc is the negative pole. This is fully explained, §§ 167 and 393.

POSITIVE.—In the battery, the zinc plate; in a decomposition cell, the anode.

Positive Pole; +, the anode, the zincode, by which the current enters another cell.

Positive Ions; hydrogen, metals, and basic radicals.

POTENTIAL.—A mathematical term much misunderstood.

The *Potential* of a battery means its E M F.

Static potential is the corresponding stress exerted in the direction of the opposite electricities and is comparable to the pressure exerted by head of water.

Potential energy is stored work, capable of again doing work, as in a lifted weight, a strained spring, or chemical decomposition.

QUANTITY.—A term based on the idea that electricity is an actually existing element, having quantitative relations to chemical actions, similar to the atomic weights of the material elements. The definition applicable to existing ideas of the nature of electricity will be found under "Current." The *coulomb* is its B.A. unit.

RADICALS.—Either elementary atoms, or compound bodies which act like atoms, retaining their completeness and individuality through a series of chemical changes. It is considered that the acids are formed of such radicals whose attractions are satisfied by hydrogen, while salts are the same radicals satisfied by metals or compound basylous radicals. These radicals are the *ions* of the theory of electrolysis.

REDUCED LENGTH.—A term formerly used to express a resistance in the terms of its equivalent length of wire or resistance. It is now superseded by the definite expression in ohms.

RELAY.—A small instrument, such as an electro-magnet, which receives a feeble current from a distance and closes the circuit of a local battery so as to produce an effect of the required degree of strength.

RESINOUS electricity.—Negative, developed by rubbing ebonite, &c.

RESISTANCE.—The opposition presented by the circuit to the development of the current; it is an inherent property of every substance, varying in degree in each substance, from silver, up to guttapercha and the other so-called non-conductors. Whatever the special substance, however, its actual resistance may be expressed in any common unit; thus we may describe the resistance of a decomposition cell as equal to so many feet of a given wire. The unit of resistance is the Ohm.

Resistance is the reciprocal of the conducting capacity of a circuit: its relations to work, &c., are explained, § 520.

Resistance requires to be considered in the various sections of the circuit as "internal," that of the battery itself; and "external," that of the work to be done, the conductors leading to it, and any measuring apparatus employed.

Resistance, when it is not work in some form, always converts the energy of the current into heat. See Ohm's Laws, and Units.

RETARDATION.—A term applied to the inductive action which reduces the rate of signalling in submarine cables. A signal to be transmitted requires a current at the receiving end adequate to the mechanical work to be performed in the instruments.

But the current which should be generated by the source is only slowly developed at the distant end, § 506, and, therefore, the signal is delayed.

RHEOMETER.—A galvanometer.

RHEOSTAT.—Resistance instrument.

RHEOTROPE.—A reversing commutator.

SECOHM.—Profs. Ayrton and Perry's name for the unit of inductance now called the Henry: but it was not of exactly the same value, being based on the then received ohm, while the Henry is related to the true unit.

SECONDARY.—An action or a circuit depending on another.

SECONDARY ACTION.—See Electrolytes.

SECONDARY BATTERY.—See Polarization of Plates.

SECONDARY WIRE, in coils, is the wire in which the induced current is set up by the magnetic reaction of the core.

SERIES.—Cells, &c., arranged in consecutive order so that the same current traverses all.

SHUNT.—A wire arranged to carry off a definite proportion of a current: a bye-pass to an instrument; another branch road as in railways, from which the term comes.

SOLENOIDS.—Helices of wire, which act as magnets.

SWITCH.—See Commutator.

TENSION.—The strain put upon the circuit by the electromotive force; it may be regarded as a single amount, or as + and − equal in opposite directions from the source. This term used to be employed in the sense now covered by potential.

THERM.—A recent name for the "calory" or water "gramme, degree, cent.," heat unit.

THOM.—This name has been suggested for the unit "magnetic induction," B, § 961; i.e. for the one "line of force," § 968.

THOMSON EFFECT.—See § 1395.

TORQUE.—The circumferential stress tending to twist or turn an axis: it is the strain exerted by the magnetic fields in a motor.

UNITS.—The various bases of any system of measurement.

The Absolute are based upon the units of mass, length, and time, such as 1 gramme, 1 metre, and 1 second.

The C.G.S. system, in which the centimetre replaces the metre, is now generally adopted. Its unit of *force* is the *dyne*, and of *energy* the *erg*, and a complete system of electric values are related to these.

The B.A. system (the British Association), now universally adopted, is based upon the preceding, but consists of named units of convenient magnitude, as follows:—

Electromotive Force and Potential.—The *volt* = 10^8 C.G.S. units.

The Daniell's cell, that is, the chemical affinity of zinc displacing copper from its union with sulphuric radical, is 1·079 volts; and therefore, for rough purposes, may be taken as a volt.

Resistance, the *ohm* = 10^9 C.G.S. units.

Current.—The *ampère*, $\frac{10^8}{10^9} = 10^{-1}$, or ·1 C.G.S. unit.

Quantity.—The *coulomb*, the same value as the ampère-second.

Energy.—The *joule*, the work done by one ampère, in one ohm, during one second.

Power.—The *watt*, 1 ÷ 746 of a horse-power, expended in doing 1 joulad of work.

VEBER.—Old name of the ampère.

VITREOUS ELECTRICITY.—Positive, developed by rubbing glass.

VOLT.—The unit of electromotive force and potential. See Units.

VOLTAMETER.—An apparatus for measuring the current by its chemical action; the term is usually limited to a vessel provided with two platinum poles for the decomposition of dilute acid, and with tubes for collecting and measuring the gases given off.

VOLT-AMPÈRE. — Energy expended by current. See Joule, which is the same.

WATT.—The B.A. unit of "power." It can supply energy at the rate of 1 joule per second, and is equal to horse-power ·00134, § 427, or 1 H.P. = 746 watts.

ZINCODE.—Daniell's term for the anode, because, like the zinc of a battery, it dissolves.

INDEX.

(*See also "Dictionary of Terms."*)

A.

ABSOLUTE units, 207.
Absorption of light, 546.
Abstract theory, Heaviside, 171.
Acceleration, in mechanics, 208, 246.
Accumulation, in dynamos, 478.
Accumulators, secondary batteries, 155.
Acid, battery solution, work of, 114.
——, strength and E M F, 123.
——, —— in secondary batteries, 162.
Acids, organic, in depositing, 425.
Actinism, 539.
Adhesion, to prevent, 376, 380.
——, to secure, 376.
Affinity, chemical, and energy, 304.
Air, di-electric strength of, 56, 453.
—— film on surfaces, 376.
—— —— is a conductor, 590.
——, use of, in cells, 141, 148.
Alkalies in cells, 114, 127, 146.
—— in secondary batteries, 166, 170.
Alkaline nitrates in cells, 136.
Allotropy, 6, 352.
——, energy as cause of, 557, 598.
Alloys, depositing, 426.
——, resistance of, 264.
——, specific heat of, 199.
——, two orders of, 264.
Alternating current, nature of, 252, 613.
—— ——, measurements, 218.
—— (*see* Dynamos, Induced, Motors).
Alternative path, of lightning, 446.
Alum, chrome, in battery, 131.
Aluminium, depositing, 423.
—— in batteries, 137.
Amalgamation of zincs, 112.
—— in plating, 378.
—— in secondary batteries, 165.
Ammonia, not a radical, 342.
Ammonium chloride, with zinc, 145.
Ammonium chloride, dangerous in electrolysis, 365.
Ampère, the unit of current, 215.
——, chemical value of, 106, 215, 313.
Ampère-hour, 216.
Ampère-turns in magnets, 470.
Ampère's magnetic theory, 85.
Amplitude, 436, 622.
—— of sound waves, 584.
Angles, properties of, 178
Anions, 341, 621.
Anode, 341, 621 (*see* Carbon).
—— corresponds to zinc in cell, 356.
——, proper position of, 395.
——, —— size of, 396.
Aqua regia in cells, 131.
Arc, multiple, 270, 630.
—— lamps, 553.
—— ——, carbon consumption, 556.
——, voltaic, 549.
——, ——, E M F in, 552.
——, ——, light of, 551.
——, ——, products of, 552.
——, ——, resistance of, 552.
——, ——, temperature of, 550.
—— ——, welding by, 611.
Arcas plating, 412.
Armature, magnetic, 100, 468, 474.
—— of dynamos, evolution of, 481.
——, horse-shoe, actions in, 495.
—— ring, apparent, 482.
—— ——, true, 483.
—— actions in ring, 475.
——, Siemens' H, 493.
——, —— drum, 498.
Asbestos, 72.
Astatic needles, 175.
Atmospheric electricity, 437.
—— charges + and −, 344, 345.
Atomic charges + and −, 344, 345.
—— combinations, 5.

Atomic system, value of, 205.
—— weight and gas measure, 11, 351.
—— ——, table of, &c., 308.
Atomicity (*see* Valency), 4.
Atoms, 2.
——, natures units of matter, 205.
——, possibly complex, 351.
Attraction and repulsion, 20, 27, 49, 89.
——, magnetic, laws, 89, 91, 468.
——, molecular, illustrated, 319.
Auroras, 98.
Automatic transmitters, 571.

B.

B, internal magnetic lines, 462.
B.A. system of units.
B.A. resistance and the ohm.
Balance (*see* Bridge, Induction).
Ballistic galvanometer, 101.
Ball lightning, 442.
Batteries, galvanic (*see* Cells), 101.
——, arrangement of, 107, 149, 270.
——, construction of, 117, 139, 150.
——, cost of working, table, 151, 153.
——, ——, economy in, 109.
——, enclosed cells for, 139.
——, fundamental actions in, 104.
——, new and useless, 119.
——, substances used in, table, 152.
Batteries, Secondary, 155.
——, acid space in, 161.
——, alkalies in, 166, 170.
——, charge and discharge, 168, 169.
——, construction, 160.
——, E M F of, 168.
——, essential action in, 163.
——, formation of, 163.
——, gases, loss of, 169.
——, history of, 158.
——, metallic solutions in, 166.
——, + and − plate, 157.
——, proper uses for, 158.
——, resistance of, 168.
——, sulphate of soda in, 163.
——, working capacity of, 167, 168.
——, working details, 169.
——, E P S, 167.
——, Faure's 166.
——, Fitzgerald's lithanode, 168.
——, Planté and modified, 163.
——, Waddel's and Phillip's, 170.
——, Woodward's (Crompton's), 167.
Bells, electric, system, 573.
Berthelot's chemical law, 358.
Berzelius's chemical theory, 23, 352.
Bichromate of potash, 131.
—— soda, 133.
Bjerknes' experiments, 90.
Blacklead for electrotypes, 386.
Bleaching by electrolysis, 370.
Board of Trade conductor rules, 294.
B O T unit (Bot.), 217, 510.
Bound or dissimulated electricity, 61.
Bourseul and the telephone, 579.
Brass depositing, 427.
Break for coils, 520; mercury, 521.
——, double contact, 231.
Bridge, B.A., 235.
——, Wheatstone's, 225.
——, ——, construction, 228, 231.
——, —— and resistances, 232.
——, ——, ——, decimal, 221, 232.
Bright deposits of metals, 412, 418.
Britannia metal, plating on, 379, 410.
Bronzing copper, &c., 403.
Brown, J., on contact theory, 318.
Brush (*see* Discharge), alternating, 617.
——, rotating, 618.
Burgin dynamo machine, 482.
Burnishing, 412.

C.

Cable in tank, retardation, 258.
Caloric and two fluids, 22.
Calorimeters, 198.
Calory, its two values, 217, 303.
Candle fired at board, 446.
—— standard of light, 564.
—— —— energy in, 564.
Caoutchouc, properties of, 68.
Capacity (*see* Dielectric, Magnetic).
—— and surfaces, 65.
—— of cylinders, plates, &c., 67.
—— of grain of water, 452.
—— of the earth, 216.
——, specific inductive, 70, 71.
——, —— and refractive index, 68.
——, unit of, the Farad, 216.
Carbon (*see* Arc, Cells).
—— absorbs light, 547.
——, allotropic forms of, 557.
—— anodes acted on, 166.
——, artificial plates, &c., 137, 555.

Carbon, connecting to, 138, 237.
—— in batteries, 137, 322, 324.
——, resistance of, 272, 273.
——, —— and heat, 237, 273.
Carbons for arc lamps, 555.
—— for glow lamps, 562.
Cells (*see* Battery, Decomposition).
——, circulation in, essential, 140, 394.
——, each a section of circuit, 355.
——, E M F of, 107, 134; table, 323.
——, enclosed, 139.
——, fundamental distinctions, 355.
——, joining up, 107, 270.
——, single liquid, defects, 118.
——, size and force of, 107.
——, two liquid, principles, 118.
——, used as voltameter, 118, 122.
——, uses suited to, 154.
——, work capacity of, 109; table, 151.
——, acids for (*see* Names of).
——, alkalies in, 114, 146.
——, alkaline nitrates in, 136, 143.
——, aluminium as negative, 137.
——, aqua regia as oxidant, 131.
——, carbon in, 117, 137.
——, iron in, as + 116; as −, 136.
——, —— oxide and chloride, 143.
——, oxidants for, 136, 148.
——, platinum in, 137.
——, saline solutions in, 114.
——, silver in, 116; platinized, 116.
——, —— chloride (Marie Davy), 128.
——, Bennett's (tin-pot), 146.
——, bichromate of potash, 131, 141.
——, —— of soda, 133.
——, ——, Voisin's red salt, 133.
——, Clark's standard E M F, 127.
——, chlorine (Upward's), 131.
——, chromic acid, 131.
——, copper and zinc, 115.
——, Daniell's, 120.
——, ——, E M F of, 123, 311.
——, ——, flat form, 121.
——, ——, theory of, 123, 321.
——, ——, Callaud's gravity, 126.
——, ——, Meidenger, Minotto, 126.
——, dry, Gasner's and others, 147.
——, gas, Grove's, &c., 147.
——, Lalande's, copper oxide, 146.
——, lead sulphate, 129.
——, manganese, Leclanché, 129.
——, mercury sulphate, 127.
——, nitric acid, Grove's, Bunsen, 129.
——, Sanschieff's, 127.
——, silver chloride, 128.
Cells, Slater's iron, 143.
——, Smee's silver, 116.
——, ——, odds and ends, 118.
Cement, for cells and wires, 206.
——, for glass, coating, &c., 18.
C.G.S. system, 208, 210.
Charge (*see* Induction) 48, 57.
——, analogy to magnetism, 456.
——, distribution, 55.
——, effects of, 69.
——, induced, 58.
——, residual, 70.
——, on the earth, 216; sun, &c., 433.
——, theory, fluid, 29.
——, ——, molecular, 30, 59.
——, to distinguish + and − 20.
Chemical action, measurement by, 194.
—— combination and energy, 301.
—— and contact theory, 316, 318.
Chemic unit of current, 106.
—— ——, why used, 206, 315.
Chloride, of ammonium, 145, 363.
Chlorides and E M F, 363.
Choking coils, 623.
Chromic acid, 133.
Circuit, the electric, 26, 319, 623.
——, actions in, and around, 241, 353.
——, formation of the, 79, 319.
——, inductive and conductive, 66.
——, magnetic, 462, 624.
Circulation in cells, 140, 394.
Clarke's typical dynamo machine, 477.
Cleaning, for depositing, 374.
Clouds, state of, in thunderstorm, 443.
Coal, and ether hypothesis, 259.
——, work value of, 510.
Coercive force, 97.
Coils, induction (*see* Spark), 515, 522.
——, dimensions of, 524.
——, disc, construction of, 523.
——, medical, 528; pocket, 530.
—— used with telephones, 589, 595.
Colour, nature of, 536.
Colours by arc light, 551.
Coloured deposits, 372, 415.
Combination, energy of (*see* E M F), 309.
Combustion, nature of, 305.
Commutator (*see* Connections), 150, 624.
——, double contact, 231.
——, mercury cup, 188.
——, reversing, 526.
Compounding dynamo machines, 502.
Condensation, 60.

Condensers, action of, in coils. 522.
——, —— on circuit, 69, 614.
——, making, 47.
Conductance, 265, 624.
Conduction, nature of, 454.
—— in liquids, 346.
—— ——, without electrolysis, 367.
—— of heat, 264.
Conducting surface, to obtain, 386.
—— system for house, 574.
Conductivity (*see* Resistance), 263, 273.
Conductor (*see* Lightning), prime, 624.
Conductors (*see* Wires), 17, 618, 624.
——, law of cost of, 295.
——, ratio of, to currents, 292.
Connections, various, 624.
——, block and plug, 220.
——, care in arranging, 181.
—— in plating, 380, 398.
Consequent poles, 97, 625.
Conservation of electricity, 610.
—— of energy, 13.
Constancy, 110; of cells, 151.
Contact and chemical theories, 315.
Convection of heat, 291.
Conversion of electricity, 14.
Copper, black coating on, 115.
——, depositing solutions, 400, 426.
——, ——, rate of, 393, 404.
—— on zinc, lowers E M F, 124.
——, qualities of, 282.
——, refining, 424.
——, removing from silver, 380.
—— resistance, unit of, 278.
—— wires, data, 280; table, 284.
Cores of coils, 516.
—— of electro-magnets, 470.
—— of iron helix, 458.
Cosmical electricity, 433.
Cost of batteries, 125, 153.
—— of energy, electric, 511.
—— ——, mechanical, 512.
—— of light, electric, 568, 569.
—— of materials used, 152.
Coulomb, the unit of quantity, 216.
Coulomb-meters, 200.
Counter (*see* Electromotive force), 354.
Cowles' electrical furnace, 423.
Crith, a unit of volume, 205.
Critical points, actions at, 557, 598, 607.
Crystallization, water of, 287.
Current (*see* Alternating, Density), 238.
Current and energy, laws, 296, 332, 338.
—— and resistance, reciprocal, 244, 338.
—— as a spiral rotation, 490.
——, chemical relations, 106, 196, 215, 353.
——, curve of, 252, 295.
——, definition of, 238, 248.
——, diagram of actions, 242.
——, etherial theory of, 239.
——, extra, 458.
——, facts related to, 241, 253.
—— from static machines, 41.
——, hydraulic analogy, 255, 258.
——, —— and electric, difference, 243.
——, induced, theory of, 254, 261, 458
——, laws of, 242, 248, 292.
——, magnetic relations of, 181, 470, 473.
——, safe, diagram of, 295.
——, square of, and work, 332.
——, tension of, 242.
——, units of (*see* Ampère, Chemic).
Cyanide of potassium, 405.

D.

Dance of atoms, 344.
Daniell (*see* Cells), 120.
Dark lines in spectrum, 538.
Decomposition cell, action in, 355.
—— —— a condenser, 359.
——, chemical, absorbs energy, 302, 321.
Dehstrom, the, 514.
Density, 50; and surface, 57.
—— of current, 110, 391.
—— ——, unit of, 392.
—— of energy, and light, 542, 547.
Deposit, rate of, 393, 404.
Deposited metal, character of, 388, 393.
Derived circuits, laws of, 268.
Diamagnetism, 99.
Dielectrics, and transparency, 343.
——, properties of, 17, 68; table, 71.
—— (*see* Leakage, Soakage, Stress).
Dimensions, 211; table of, 211.
Dip of magnet needle, 94.
Discharger (*see* Magnetism, Spark), 73.
——, experiments on, 41.
——, brush and star, 74.
Discharger, universal, 525.

Dissimulated electricity, 30, 61.
Dissociation, 343, 368.
Distance and force, law of, 49, 52.
—— in depositing, 396.
—— of magnet and armature, 91, 468.
Distillation, destructive, 358.
Distribution, electric, 55.
—— of light, 547.
Dry batteries, 147; piles, 45.
Dual nature of electricity, 77.
—— —— magnetism, 436.
Dulong's law, not universal, 351.
Duplex telegraphy, 571.
Dynamo machines, 476.
——, and motors, distinction, 507.
——, compound, shunt-series, 502.
——, efficiency of, 505.
——, E M F of, 503.
——, evolution of, 480.
——, history of, 476.
——, resistance of parts, 504.
——, series, 501; shunt, 501.
—— (*see* Armatures, Field Magnets).
Dyne, C G S unit of force, 208, 210.

E.

Earth, the, a magnet, 94.
—— battery, 146.
——, capacity of, 216; charge, 434.
—— circuit, nature of, 287.
—— currents, 431.
——, meaning of connecting to, 31, 626.
—— not a reservoir, 23, 33.
——, plates, 448; testing, 449.
Ebonite, 34, 38, 72.
—— transmits heat rays, 546, 602.
—— tubes, to make, 518.
Eddy currents (*see* Foucault), 466, 616.
Edison effect, 566.
Effective current and E M F, 218, 566.
Elasticity, analogous to induction, 256
Electricity, nature of (*see* Dual) 14, 31.
—— not convertible to heat, 14, 197.
——, specific heat of, 608.
——, two factors of, 12, 452.
Electrics and non-electrics, 16, 26.
Electrodes, effect of size, 368.
——, liquid surfaces as, 359.
——, selection of *ions* at, 362.
Electrolysis (*see* Deposit), 341.
——, action in the liquid, 361.
——, analogy to distillation, 358.
Electrolysis, chemical affinity and, 360.
——, conduction by, 349; diagram, 356.
——, current without, 367.
——, direct and secondary, 360, 362.
——, examples of, 365.
——, experimental apparatus, 371.
——, laws of, 357; terms of, 341.
——, theories of, 343, 357.
——, work done in, 358, 404.
Electrolytes, definition of, 348, 367.
—— in derived circuits, 364.
——, mixed, action in, 363.
—— need different E M F, 354.
——, Ohm's law with, 348, 349.
—— (*see* E M F counter, Water).
Electro-magnetism (*see* Magnetism).
Electro-metallurgy (*see* Names), 374.
——, anodes in, 439; test work, 411.
——, arrangement of objects, 394.
——, —— of works, 425.
——, E M F needed in, 389.
——, laws of, 387, 402.
——, preparation of objects, 376.
——, vessels for, 380, 418.
Electro-meters, 42; Thomson's, 43.
—— measure potential only, 50.
—— —— in own circuit only, 57.
E M F (*see* Potential) 106, 298.
——, apparatus, experimental, 300.
——, chemical affinity and, 312, 329.
——, for electrolysis, 389.
——, high, economy of, 296, 513.
—— is a form of energy, 103, 329.
——, is it a force ?, 245.
——, measurement of, 298.
—— of cells, 124; table, 323.
—— of + and − metals, 327.
——, origin of, in cells, 102, 156, 245.
—— set up by light, 559.
——, unit of, the Volt, 213.
E M F, *counter*, 268, 354, 358.
——, ——, as a resistance, 268.
——, ——, electrolytic work as, 359.
——, ——, of motors, 508.
Electrophorus action of, 28.
——, making, 18, 28.
Electroscopes, 19, 21.
——, Bohnenbergers, 45.
——, condensing action, 61.
Electrotype, 375.
Elements, 2; table, 308.
Elmore's process 402, 405.
Emery, discs and straps, 377.
Endosmose, electric, 120, 627.
Energy (*see* E M F, Transmission), 13.

Energy, capacity to absorb, 602.
——, conservation of, 13.
——, cost of (*see* Cost) 511.
——, density of, in light, 547, 549.
——, potential, stress, 102, 247.
—— of currents, 241, 339.
——, fixed and fluctuating, 301.
——, intrinsic or specific, 304, 307.
——, ——, of elements; table, 308.
——, relations of, to matter, 101, 301.
——, transfer of, ether theory, 239, 485.
——, transmutations of, 318, 549.
——, unit of, the Erg, 209.
——, ——, —— Joule, 216.
"English Mechanic," telephone, 583.
Equi-potential lines, 78, 614.
Equivalence, apparent exceptions, 351, 361.
Equivalent, 308, 627.
——, electric, 308, 312, 353.
——, notation, 11.
Equivolt, the, unit of energy, 313, 315.
—— on the Gramme system, 330.
——, why used, 205, 315.
Erg, the, unit of work, 209, 315.
Ether, the, 3, 24.
——, fallacies about, 171, 240, 259.
——, relation of, to light, 539.
——, transmission theory, 239, 485.
——, ——, origin of, 251.
Evaporation and electricity, 439.
Evolution theory, 479.
Ewing, Prof., magnetic theory, 465.
Excelsior, 505.
Experiments, 17, 371, 395.
——, simplest, are the best, 31.

F.

Farad, the unit of capacity, 216.
Faraday, on force of lightning, 451.
Ferric salts, electrolysis of, 419.
Field, magnetic, 459, 474, 615.
——, —— displacement of, 475.
——, —— resistance to crossing, 474.
—— magnets, 491, 500.
—— of force, 21, 27, 58.
—— ——, mechanical imitation, 90.
—— ——, optically shown, 69.
Flames and discharge, 41.
——, temperature of, 543.
Flashing carbons, 555, 563.
Fluid theories, 22.
Fluid theories, absurd results of, 24.
Fluorescence, 538.
Foot-pound, value in ergs, 209.
Force (*see* E M F, Mechanico-motive).
——, definitions of, 11, 51.
——, general views of, 51, 246.
——, lines of (*see* Field), 320, 464, 487.
——, static and dynamic, 246.
Formulæ, use and misuse of, 340.
Foucault currents, 457, 466.
Friction, how it produces electricity, 27.
Frictional machines, 34.
Fuel, energy of, 510.
Fumes in batteries, to avoid, 150.
Furnaces, electric, 423.
Fusible alloys, 381.
Fusion and electricity, 200.
——, points of, table of, 199.

G.

g, symbol of gravitation, 246.
Galvanometer (*see* Needles), 172, 177.
——, ballistic, 193.
——, control magnets for, 192.
——, deflections, valuing, 178, 182.
——, differential, 189.
——, earth's magnetic effect, 179.
——, graduation, curves of, 185.
——, —— for depositing, 373.
——, ordinary, horizontal, 183, 187.
——, resistance indicating, 186.
——, —— proper for, 194, 230.
——, sine, 182.
——, solenoid, 193.
——, stand for, rotating, 176.
——, tangent, 180; laws of, 181.
——, Thomson's reflector, 190.
——, vertical, 188.
——, wires of, varying effect of, 183.
Gas as fuel, energy of, 511.
—— burners, double, 544.
——, light from, 544.
——, the share panic, 548.
——, volume and valency, 196.
Gases, absorption heat of, 309.
——, cooling action of, 291.
——, loss of, in secondary battery, 163.
——, relation of, to energy, 602.
——, unit volume of, 196.
Gasification, latent energy of, 328.
Gauss, the, unit, 95, 628.
German silver (*see* Wires), 273, 283.

German silver in galvanometers, 194.
Gilding (*see* Colour), 415.
Glass, qualities of, 34, 72.
——, absorption of light by, 546.
——, moisture on, 18.
Glow lamps (*see* Incandescent), 556.
Glue, marine, 382.
Gold, to remove, 379.
—— in fusion, 557.
Gower's transmitter, 594.
Gramme, dynamo, 494.
Gravitation, nature and laws, 208, 246.
—— and planetary charges, 434.
Gravity, *g*, symbol, value of, 246.
——, specific, table of, 199.
Grindstone, illustration, 16.
Gutta-percha, 72; moulds, 382.

H.

H, magnetic horizontal intensity, 95.
H, magnetizing force, 462.
H armature, Siemens, 493.
Head of water, 248.
Heat (*see* Energy, E M F, Resistance).
——, atomic and molecular, 12, 556.
——, conduction, laws of, 290.
——, convection of, 291.
——, dissipation of, 290.
——, effects in batteries, 124, 140.
——, —— in wires, 204, 557.
——, mechanical equivalent of, 302.
——, of current, 197, 200.
——, of solution, 309.
——, specific, 199, 275; table, 199.
Helices, right and left, 459, 487.
Helix, bar entering, 484, 488.
Henry, the unit of inductance, 218.
Hertz experiments, 262, 436, 612.
—— on Clerk-Maxwell's theories, 539.
Homologous series, 480.
Horizontal intensity, earth's, 95, 179.
Horse-power, values of, 510, 628.
——, light per, 563.
House wiring system, 574.
Hughes, Prof., induction balance, 604.
——, magnetic theory, 87.
——, on oil insulation, 534.
Hydraulic analogies, 14, 255, 261, 337.
Hydrochloric acid in cells, 114, 132.
Hydrogen, a metal, 101.
——, unit volume, 196, 205.
—— peroxide, action, 368.
Hypothesis, use and dangers of, 4.
Hysteresis, 464; law of, 533.

I.

I, intensity of magnetism, 464.
Impedance, 267, 446, 586.
Incandescent lighting, 556.
—— ——, cost of, 564, 568.
—— ——, real advantages of, 565.
—— lamps, carbon, first use of, 558.
—— ——, —— film forms in, 547.
—— ——, ——, form of wire, 562.
—— ——, ——, how it breaks, 566.
—— ——, duration or life of, 565.
—— ——, early, 560.
—— ——, Edison effect in, 566.
—— ——, efficiency of, 564, 568.
Inch, cubic, of water, &c., 196, 277.
Independent, nothing is, 483, 595.
Index notation, 209.
Induced charge, 58 (*see* Current).
Inductance, 218; a — E M F, 268.
Induction and charge, 33, 48.
—— balance, Hughes', 604.
——, effect on telephones, 586.
—— machines, 35, 41.
——, polar theory of, 78.
Inductive circuit, 63, 66.
Inductophone, W. Smith's, 602.
Influence machines, 35, 41.
Insects, depositing on, 385.
Insulating materials, 72.
—— ——, specfic resistance of, 286.
—— stand and holder, 17.
Insulation of coils, 519.
—— cools wires, 290.
Interdependence (*see* Independent).
Introversion, magnetic, 497.
Ions, classification of, 341, 629.
—— do not exist free, 345.
——, migration of, 346.
——, transfer of, 359, 370.
Iridium, depositing, 423.
Iron, amalgamating, 416.
——, depositing, 419.
——, —— metals on, 401, 416, 426.
——, in batteries, bad, 116, 136.
——, magnetic capacity of, 465.
——, quality for dynamos, 503.
—— wire, data of, 278.
—— ——, bad for conductors, 291, 592.
—— —— core, current in, 458.
Isomerism, 8, 304, 352.

J.

Jablohkoff candle, 554.
Jars (*see* Leyden, Porous)
Joule, the, unit of energy, 216.

L.

Ladd's dynamo machine, 478.
Lag, 466, 617.
Lamps (*see* Arc, Incandescent).
Lateral transfer, alleged, 259.
Law of least energy, 357, 430.
——, meaning of, in science, 27.
Lead, depositing, 434.
—— sulphate, reduction of, 164.
——, thickness for cells, 161.
Lead of dynamo brushes, 475, 507.
Leads (*see* Conductors, Wires).
Leakage, in dielectrics, 69.
——, magnetic, 466.
Lenz's law of induction, 458.
Leyden jar, 46; theory of, 64.
Light (*see* Distribution, Photometry, Spectrum).
——, all sources identical, 548.
—— and electricity, same velocity, 211.
——, an octave of wave lengths, 538.
——, Clerk-Maxwell's theory of, 435.
——, effect of, on discharge, 76.
——, —— on resistance, 265.
—— has no actual existence, 535.
——, mechanical equivalent of, 542.
——, not electric vibrations, 541, 543, 548.
——, not etherial in nature, 539.
——, refractive index and induction, 68, 437.
——, relation of, to electricity, 437, 542.
——, units of; standard candle, 545.
——, unlike magnetism, 436, 541.
——, electric, cost of, 568, 569.
——, ——, energy in, 564.
——, ——, history of, 548, 558, 561.
——, ——, ratio to current, 566.
Light-house, lights for, 552.
Lightning, affects magnets, 94.
——, ball, 442; sheet, 441.
——, covers a large area, 444,
—— conductors, principles, 447.
—— ——, earths for, 448.
—— —— not to be insulated, 449.
Lightning conductors, testing, 448.
——, current of, 453; E M F, 445.
——, dark flashes in photographs, 445.
——, death by, painless, 444.
——, distance of, 443.
——, energy in water and, 439, 451.
—— flash, length and time of, 442, 443.
——, lateral discharge, 446.
——, light of, 443.
——, marks caused by, 444.
——, spirality of, 445.
Lines of force, 50, 464, 614.
——, action of cutting, 473.
Liquids, law of conduction, 287.
——, resistance of, table, 135, 286.
——, —— measuring apparatus, 289.
——, structure in, 286.
Lithanode, 146, 168.
Logarithms, value of, 276.
Lyre, Wheatstone's, 596.

M.

Machines, frictional, 34; influence, 35.
Magnetance, 241, 253, 629.
Magnetic attraction, 88.
—— capacity, 82, 97, 465.
—— circuit, 462, 623.
—— curves and field, 81, 95, 461.
—— fluids, 81; force, 191.
—— induction at middle, 460.
—— intensity (*see* Horizontal), 97, 465.
—— lines (*see* Curves), 82.
—— moment, 96.
—— needles (*see* Needles), 173.
—— poles, 95, 457.
—— rings around conductor, 241, 486.
—— storms, 99, 432.
—— symbols, 462.
—— theories, 85, 87, 465.
—— variation, 94, 179.
Magnetising processes, 92, 173.
Magnetism, analogy to charge, 456.
—— and atomic values, 86.
—— a static force, 83.
—— at right angles to electricity, 83, 485.
——, not radiant, nor undulatory, 435.
——, sounds produced by, 584.
——, space and, 434.
——, stores energy, 100, 252, 455,
——, terrestrial, 94.

Magneto-motive force H, 463.
Magnets and currents, 84, 459, 485.
——, electro, 467; wires for, 472.
——, evolution of forms of, 481.
——, form and construction, 93, 467.
—— have no inherent force, 100.
——, lifting power of, 468.
——, molecular structure, 82, 455.
——, preservation of, 93.
——, steel suited for, 92
—— (*see* Attraction, Field, &c.).
Manganin, new alloy, 629.
Mathematics, dangers of, 342, 434.
Maxwell, Clerk, electrical theories, 21, 343.
——, ——, Hertz's criticism of, 539.
——, ——, theory of light 435.
Measurement, principles of, 171, 204.
—— by chemical action, voltameters, 194.
—— by heat, calorimeters, 197.
—— by magnetism, galvanometers, 172.
——, the atom, natures unit of, 205.
Mechanical equivalent of heat, 302.
—— —— of light, none possible, 542.
Mechanico-motive force, 246.
Medical action of coils, 530.
Metals, E M F of, 326.
——, resistance of, 273.
——, to remove, in plating, 379.
Melting points of metals, 199.
Mercury contact break, 521.
—— cups and connections, 149.
——, economy in using, 112.
Meters, electric, 200.
Mho, unit of conductance, 266.
Micro-farad, of capacity, 216.
Microphone, Hughes', 587.
Micro-tasimeter, Edisons, 605.
Mitis metal, 465.
Molecular chain, 319 (*see* Polarization).
—— disturbance and electricity, 26, 318, 607.
—— motion, Tyndall on, 25.
—— order due to sum of forces, 483.
—— theory of electricity, 24.
—— types and construction, 7, 350.
Molecules, 6, 9.
—— compared to solar system, 9.
Momentum, 246.
Moon and earth's magnetism, 432.
Motion, use of in depositing, 399.
——, rythmic and undulatory, 535.
Motograph, Edison's, 572.
Motor generators, 534.
Motors, electro-magnetic, 505.
——, cost of working, 509.
Moulds, elastic, 384; fusible, 381.
——, plaster, and composition, 380.
Musical instruments, electric, 572.
—— notes, nature of, 536.

N.

N, symbol of magnetic lines, 464.
Nascent actions, 362, 629.
Needles for galvanometers, 173.
——, strength of, and deflections, 176
——, swings of, law of, 174, 193.
Negative plate, actions at, 321, 327.
Nickel plating, 417.
Nitric acid, electrolysis of, 130.
—— —— fumes, to collect, 150.
—— ——, strength of, 129.
—— —— ——, effect on E M F, 324.
Nitrogen, chloride of, 363.
Notation, chemical, 10, 630.
—— index, 209.

O.

Objects, disconnected, in vats, 400.
Occlusion of gases, 156, 630.
Ohm, the, unit of resistance, 213.
—— and the B A unit, 266.
——, different values for, 214.
—— standard, suggested form, 215.
Ohm's formulæ, 215, 244, 630.
—— —— as related to mechanics, 242
—— —— —— to energy, 249, 354.
Oil insulation, 533.
Organ, electric, 572.
Oscillations, electric, 267, 541.
——, what they are, 446.
Oscillator, Hertz, the, 612.
Osmose, 120, 630.
Oxidants, action of, in cells, 325.
——, ——, diagram of, 134.
Ozokerit, 72.
Ozone, nature and production, 368.

P.

π 4, meaning of, 468.
Pacinnotti ring, 479.
Page effect, 631.
Pail experiment, Faraday's, 58.
Palladium absorbs hydrogen, 156.

Paraffin, and uses of, 73.
——, wood saturated with, 28.
Patent law, just, 561.
Peltier effect, 608.
Pendulum, law of, 174, 534.
Permeability, μ, 463, 465.
Permeameter, 469.
Permittance, 463, 631.
Peroxide of lead, 145.
Peroxides, depositing, 371.
Petroleum as fuel, 511.
Phase, 466, 617.
Phlogiston, potential energy, 13, 304.
Phonautograph, Scott's, 578.
Phonograph, Edison's, 578.
Phosphorus solution, 385.
Photometry, 545.
Photophony, 596, 600.
Photo-telegraphy, 603.
Physical state and energy, 101, 301.
Piles, dry, 45.
Pipes, friction of water in, 248.
Planté and secondary batteries, 159.
Plaster of Paris, 382.
Platinic hydrate, 422.
Platinized glass, 598.
—— silver, 116; E M F of, 327.
Platinum chloride, 421.
—— depositing, 420.
Plumbago for electrotypes, 386.
Points, action of, 56.
Polar induction, dual, 78.
Polarization, nature of, 10, 25, 319.
——, electric and magnetic differ, 83.
—— of light, 540; electric waves, 615.
—— of plates,—E M F, 140, 155, 358.
—— —— in Daniell, and cells, 125, 359.
—— set up at + metal, 320.
—— —— in both directions, 77, 242, 258.
Poles and plates, 104, 157.
—— ——, magnetic, unit, 95.
—— ——, N and S, French names, 100, 457.
—— ——, not necessarily equal, 468.
Porous jars, 119; resistance, 283.
Position of objects, 394.
Positive and — electricity unlike, 74.
—— —— to distinguish, 20.
—— metals, E M F of, 326.
Potential, definitions of, 53, 63.
——, as pressure, 61, 226.
——, distribution of, in circuit, 226.
——, fall or slope of, 254, 336.
—— of the atmosphere, 437.
Potential, relation of, to E M F, 54.
—— —— to energy, 336.
Powders, effect of heating, 382.
Power (*see* Horse), Watt, unit, 217.
Preparation of objects, 376.
Pressure, electric = potential, 225.
Proof plane, 28.
Pushes, 576.

Q.

Quadruplex telegraphy, 571.
Quantity, dynamic, 153, 349.
——, electro-static, 49.
——, ——, has no existence, 14.
——, the Coulomb unit of, 216.
——, magnetic, 95.
Quantities, the two factors of electricity, 14, 337, 452.
Quicking in plating, 378.

R.

Radiation of heat, 291; light, 558.
Radiations, the Hertz, 614.
Radiant energy, actions of, 596, 614.
Radiometer, Crookes', 596.
Radiophony, 595.
Rain and lightning, 439.
Reciprocals, 249.
Refining lead and copper, 424.
Reflection, electric, 615.
Regulator of resistance, 390.
Relay, 633.
Repulsion, Clerk-Maxwell on, 21.
——, nature and laws of, 21, 51.
——, electro-magnetic, 615.
Repulsive force, none in nature, 51.
Residual charge, 70.
Resistance, as a velocity, 266.
——, *electrical*, so called, 106, 248, 266.
——, ——, errors about, 243.
——, ——, laws of, 248, 268.
——, mode of measuring, 225.
——, reciprocal of conductance, 244, 248.
——, relation of, to time, 338.
——, specific, per cub. cent., 263, 273.
——, temperature effects on, 265.
——, unit of the ohm, 213.
——, work acting as, 267.
——, why equal for all currents, 249.
——, *true*, means work, 244.

Resistance, measurement of, 195, 225.
——, ——, instruments for, 219, 221, 231.
——, variable, construction, 236, 390.
——, *magnetic*, 464.
Resistances, arc and consecutive, 268.
—— of batteries, to measure, 270.
—— of carbon, 272.
—— of dielectrics, 68.
—— of galvanometers (a loss), 194.
—— of liquids, 283; table, 134, 286.
—— ——, apparatus for, 288.
—— of metals (*see* Wires); table, 273.
—— in electro-metallurgy, 390.
Retardation, 70, 258, 632.
Reversing commutator, 526.
Rheostats, 219, 633.
Ring armature, actions in, 494.
Rotary magnetic field, 514.
Rotation of molecules, 454.
—— of polarized light, 344.

S.

Saturation, magnetic, 97, 464.
Sal-ammoniac, actions of, 145, 363.
Salt, action of, in cells, 114, 145, 324.
——, electrolysis of, 369.
Salts, theory of, 306.
Secondary (*see* Batteries), 155, 633.
—— wire in coils, 519.
Selenium and light, 597.
—— cells construction, 599.
Scales for reflectors, 191.
Science, ancient and modern, 171.
Shellac, 73; varnish, 18.
—— solution, a conductor, 73.
Shielding actions, 603, 616, 617.
Ships, action of, on wind, 441.
Shunts, law of, 269.
Siemens' H core, 477, 493.
—— drum dynamo, 498.
Silver, ampere equivalent of, 215.
—— depositing, 407.
——, bright deposit, 412.
——, to dissolve off, 379.
—— sulphide, uses of, 599.
Sine galvanometer, 182.
Sines, the law of, 177.
Siren, the, 580, 596.
Size, does not affect E M F, 107.
Skin current explained, 258.
Slate, uses of, 73, 618.
Slugs, use for, 386.
Smee's laws of electro-metallurgy, 387.
Soakage in dielectrics, 69.
Soda, caustic, solution, 378.
Solar system, as molecular type, 9.
Soldering wires, 531.
Solids give all rays, 542.
Solubility of salts, 400.
Solution, + and − heat of, 310.
Solutions, proper strength of, 389, 393.
——, depositing, qualities of, 399.
——, ——, spoilt, treatment of, 413 414.
Solvent, action of, in electrolysis, 346.
Sonometer, Hughes', 605.
Sound, nature of, 536, 595.
——, signals given by, 601.
Sounds, produced by heat, 602.
Spark (*see* Discharge), laws of, 524.
——, duration of, 76.
——, qualities of, 75.
——, spectrum of, 75.
Spectrum, the, 537.
——, development of the, 542.
Spiral rotation of current, 490.
—— theory of magnetism, 87.
—— track of lightning, 445.
Spires (turns), equal action of, 470.
Sphere (*see* Capacity), enclosed, 62.
Speed and E M F of dynamos, 492.
Squares, law of, meaning of, 336.
—— of distance and energy, 547.
Stand, insulating, 19, 28.
——, rotating, for galvanometers, 176.
Static and dynamic electricity, 66.
—— electricity, a misnomer, 17.
—— —— and heat, relations, 16.
Steel, non-magnetic, 465.
—— suited for magnets, 92.
Stopping off, varnishes, &c., 387.
Storms, magnetic, 432.
Stress in dielectrics, 29; visible, 68.
——, breaking down limit, 56, 69.
Striking in electro-metallurgy, 410.
Stroh's experiments, 91.
Structure in liquids, 286.
—— of matter, 349.
Substitution, atomic, 7.
——, specific energy of, 311.
Sulphuretted hydrogen from paraffin, 73.
Sulphate of soda in accumulators, 163.
Sugar, electrolytic, fraud, 372.
Sulphuric acid, strength, &c., 113.
Surfaces, action of, 32, 55, 57.
——, to make conducting, 385, 386.

Swan, and glow lamps, 558.
Swinburne's experiments, 618.
Swings of needle, law, 174, 193.
Switches (*see* Commutator), 577.

T.

Tangent galvanometer, 180.
——, scale and law of, 178.
Telegraphy, 570.
Telephone (*see* Transmitter), 579.
——, Bell's, construction, 582.
—— circuit, disturbances, 586.
——, current required for, 581.
——, disc, motion of, 584.
——, distance available for, 592.
——, Dolbear's induction, 585.
——, history of the, 579.
——, inductance in, 586.
——, induction coils with, 595.
——, Paris and London, 593.
——, sensitiveness of, 586.
——, speech with, law of, 592.
——, system and circuit, 594.
——, to test electro-magnets, 476.
Temperature and currents, 292.
—— (*see* Wires) correction for, 273.
——, relation to density of energy, 542.
——, —— to wave lengths, 542.
——, resistance of high, 275.
——, safe, for conductors, 294.
——, table of degrees of, 543.
Tension, different views of, 53, 617.
—— in electro-metallurgy, 392.
Terms, old and misleading, 22.
Terrestrial magnetism, 94, 431.
Tesla's experiments, 541, 617.
Theory, real use of, 1.
Therm, the, 303, 633.
Thermo-chemistry, 304.
—— electricity, 606.
—— piles, 609.
Thermo-phone, 602.
Thomson effect, 608.
Thunderstorm, distance of, 443.
——, nature of, 440, 443.
Torque, 633.
Torsion, law of, 42.
Tractive force, magnetic, 467.
Transformers, 532.
Transmission of energy, 512, 618.
——, high E M F in, 243, 296, 513, 618.
Transmitters, photophonic, 601.
——, radiophonic, 596.
——, telegraphic automatic, 571.
——, telephonic, 587.
——, telephotographic, 603.
Trigonometry, terms of, 177.
Tubes of force, 464.
Types, molecular, 7.

U.

Undulations, not electric, 613, 615.
Unipolar actions, supposed, 80.
Unit, the natural, and system, 205.
Units, absolute, 207, 212, 633.
——, B.A. system, 207 ; practical, 212.
——, C.G.S. system, 207.
——, relations among, 303, 633.
——, table of electric, 211, 219.
——, ——, general conversion of, 314.

V.

v ratio and velocity of light, 211.
Vacuum tube experiments, 80.
Valency, 4, 351.
Vapour in air stores energy, 439.
Variation, magnetic, 94, 179, 432.
Varley and accumulation, 35, 478.
Varnish, electric, 18.
Velocity of electricity, 76.
—— of light, 211.
Vessels for electro-metallurgy, 380, 418.
Viscosity, magnetic, 466.
Vision, persistence of, 40, 443.
Vis viva, 208.
Volt, unit of E M F, 213.
——, possible standard, 213.
—— is static pressure, 213, 312.
Voltage, name for E M F, 298.
Voltance, energy of E M F, 253, 315.
Voltameters, 194.
——, battery cells as, 118, 122, 195.
Volt-ampère, 217.
—— —— hour, 217.
Voltmeters, 193, 300.
Volume, atomic and molecular, 158, 557.
Vulcanized fibre, 73.

W.

Walls, charge on, 50, 58.
——, electric function of, 32.
Waste in electrolysis, 425.
Water, electrolysis, E M F, 331, 361, 366.
——, ——, supposed cases, 366, 368.
—— is not an electrolyte, 366.
——, molecular construction of, 8.
——, supposed energy stored in, 451.
——, weight of cubic inch, 277.
Waterspouts, 440.
Watt, the unit of power, 217.
Watts per candle of light, 564.
Waves of water, radial action, 614.
Wax compositions, 383.
Weber, unit magnetic pole, 95.
Welding, electric, 611
Wheatstone's (*see* Bridge) lyre, 596.
Wilde's dynamo machine, 477,
Wimshurst's machine, 36.
Wire crossing magnetic field, 489.
Wires, constants and formulæ of, 278.
—— cooled by insulation, 290.
——, copper, data, 280 ; table, 284.
——, cost of, proper ratio, 296.
——, dimensions of, 275, 277.
——, gauges, 276.
Wires, German silver, data, 282.
——, ——, sizes for resistances, 223.
——, hardness and conductance, 264.
——, heat developed in, 198, 289.
——, —— safe, 294.
——, management of, 530.
——, platinum, heat in, 199.
——, quantity on magnets, 472.
——, relation of, to covering, 472.
——, safe current in, 294.
——, weight per *mil-foot*, 277.
Wood, to make insulating, 28, 73.
Work (*see* Energy, Resistance).
——, internal molecular, 13, 353.
——, is as square of current, 332.
——, of electrolysis, 373, 404.
——, reduces current, 267.
——, units of (*see* Erg, Joule).

Z.

Zinc, E M F of, 321.
——, ——, effect of copper on, 124.
—— for batteries, 111.
—— in batteries, action of, 101
——, potential energy of, 304.
——, recovery of, 115.

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